

ADA077887

14  
AEDC-TSR-79-V29

11 MAY 1979

LEVEL II

12 47 6  
THERMAL RESPONSE AND REUSABILITY TESTS OF  
ADVANCED FLEXIBLE REUSABLE SURFACE INSULATION (PSI) AND  
CERAMIC TILE RSI SAMPLES AT  
SURFACE TEMPERATURES TO 1200°F.

10  
E. C. Knox

ARO, Inc., AEDC Division  
A Sverdrup Corporation Company  
von Karman Gas Dynamics Facility  
Arnold Air Force Station, Tennessee

Final rept.

Period Covered: April 4-5, 1979

DDC

DEC 11 1979

Approved for public release; distribution unlimited.

DDC FILE COPY

Reviewed By:

Ervin P. Jaskolski

ERVIN P. JASKOLSKI, Capt, USAF  
Test Director, VKF Division  
Directorate of Test Operations

Approved for Publication  
FOR THE COMMANDER

James D. Sanders

JAMES D. SANDERS, Colonel, USAF  
Director of Test Operations  
Deputy for Operations

Prepared for: NASA/JSC  
Houston, TX 77058

ARNOLD ENGINEERING DEVELOPMENT CENTER  
AIR FORCE SYSTEMS COMMAND  
ARNOLD AIR FORCE STATION, TENNESSEE

79 12 11 052  
143,560

# UNCLASSIFIED

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AEDC-TSR-79-V29 ✓	2. GQVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Thermal Response and Reusability Tests of Advanced Flexible Reusable Surface Insulation (RSI) and Ceramic Tile RSI Samples at Surface Temperatures to 1200°F	5. TYPE OF REPORT & PERIOD COVERED Final Report April 4-5, 1979	
	6. PERFORMING ORG. REPORT NUMBER	
7. AUTHOR(s) E. C. Knox, ARO, Inc., a Sverdrup Corporation Company	8. CONTRACT OR GRANT NUMBER(s)	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Arnold Engineering Development Center ✓ Air Force Systems Command Arnold Air Force Station, Tennessee	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Program Element 92/E01 AF Control No. 9E01-Q0-8	
11. CONTROLLING OFFICE NAME AND ADDRESS NASA/JSC Houston, TX 77058	12. REPORT DATE May 1979	
	13. NUMBER OF PAGES 44	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report)  Unclassified	
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A	
16. DISTRIBUTION STATEMENT (of this Report)  Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)  materials test insulation flexible fabric ceramic temperature exposure		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Ten minute exposure tests were performed on samples of an advanced flexible reusable surface insulation (AFRSI) made of a quartz glass fabric and samples of a ceramic tile reusable surface insulation (RSI). Tests were performed at free-stream Mach number 10 with a total pressure and temperature of 1200 psia and 2150°R, respectively. Samples were inclined to the flow at 25 deg and heated to about 1660°R during exposure.		

DEGREE

## CONTENTS

	<u>Page</u>
NOMENCLATURE . . . . .	2
1.0 INTRODUCTION . . . . .	4
2.0 APPARATUS	
2.1 Test Facility . . . . .	4
2.2 Test Article . . . . .	4
2.3 Test Instrumentation	
2.3.1 Test Conditions . . . . .	5
2.3.2 Test Data . . . . .	5
3.0 TEST DESCRIPTION	
3.1 Test Conditions and Procedures	
3.1.1 General . . . . .	6
3.1.2 Data Acquisition . . . . .	6
3.2 Data Reduction	
3.2.1 IR System Photographs of Sample Surface Temperature . . . . .	7
3.2.2 Sample Temperatures . . . . .	8
3.3 Uncertainty of Measurements	
3.3.1 General . . . . .	9
3.3.2 Test Conditions . . . . .	10
3.3.3 Test Data . . . . .	10
4.0 DATA PACKAGE PRESENTATION . . . . .	10
REFERENCES . . . . .	11

## APPENDIXES

### I. ILLUSTRATIONS

#### Figure

1. Tunnel C . . . . .	13
2. Sample Photographs . . . . .	14
3. Sample Details . . . . .	18
4. Installation Photograph and Sketches . . . . .	22
5. Sample Thermocouple Locations . . . . .	25
6. Photographs of Damaged Samples . . . . .	27
7. Sample AFRSI Spectral Emissivity . . . . .	29
8. Black Body and AFRSI Total Emissivity . . . . .	30

### II. TABLES

1. Test Summary . . . . .	33
2. IR System Color Calibration . . . . .	34

### III. SAMPLE DATA

1. Tabulated Data . . . . .	36
2. Plotted Data . . . . .	38
3. Typical IR System Photograph of the Surface Temperature . . . . .	44

# NOMENCLATURE

ALPI	Indicated pitch angle at lift-off, deg
AMES SENSOR	Output of radiometer, mv
CONFIG NUMBER	Sample number 1, 2, 3, or 4
CR	Center of Rotation, axial station along tunnel centerline about which the wedge rotates, in.
$e_{b\lambda}$	Black body emissivity at 530°R
ITT	Enthalpy based on stilling chamber total temperature, Btu/lbm
M	Free-stream Mach number
MU	Coefficient of viscosity based on free-stream temperature, lbf-sec/ft <sup>2</sup>
P	Free-stream static pressure, psia
PHII	Indicated roll angle, deg
PT	Total pressure measured in the tunnel stilling chamber, psia
Q	Free-stream dynamic pressure, psi
RE	Free-stream unit Reynolds number, ft <sup>-1</sup>
RHO	Free-stream density, lbm/ft <sup>3</sup>
RUN	Data set identification number
SAMPLE POSITION	0 or 180 degrees, 0 denotes small RSI tiles on right side of wedge looking downstream, 180 deg-reversed
TAW	Adiabatic wall temperature, °R
T	Free-stream static temperature, °R
TT	Total temperature measured in the tunnel stilling chamber, °R
TC1	Output of thermocouple 1 on sample, °R
TR1, TR2	Measured reference temperature at connector, °R

TIMECL	Time at which the wedge reached tunnel centerline, CST
TIMEEXP	Time of exposure to the tunnel flow when data were recorded, sec
TIMEEXPT	Total exposure time for a RUN, sec
TIMEINJ	Elapsed time from lift-off to arrival at tunnel centerline, sec
V	Free-stream velocity, ft/sec
WA	Wedge angle with respect to free-stream, deg
$X_{\lambda}$	IR camera spectral response factor
$\epsilon$	Fabric sample total emissivity
$\epsilon_{\lambda}$	Fabric sample spectral emissivity
$\lambda$	Wavelength, microns
SUBSCRIPTS	
w	Wedge flow conditions

1. Date	10/10/67
2. Time	1:30 PM
3. Location	100 ft. from tunnel entrance
4. Description	Wedge flow conditions
5. Investigator	
6. Availability Codes	
7. Initials and/or Signature	A

## 1.0 INTRODUCTION

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 921E01, Control Number 9E01-00-8, at the request of the National Aeronautics and Space Administration (NASA), Johnson Space Center (JSC), Houston, Tx, for the NASA, Ames Research Center (ARC), Mountain View, Ca. The NASA-JSC project monitor was Mr. Bill Moseley (ES3) and the NASA-ARC project monitor was Mr. Howard Goldstein. The results were obtained by ARO, Inc., AEDC Division (a Sverdrup Corporation Company), operating contractor for the AEDC, AFSC, Arnold Air Force Station, Tennessee. The test was conducted in the von Karman Gas Dynamics Facility (VKF) Hypersonic Wind Tunnel (C) on April 4 and 5, 1979, under ARO Project No. V41C-56.

The test objectives were to determine the thermal response and reusability of Advanced Flexible Resuable Surface Insulation (AFRSI) materials. Sample materials were exposed to a controlled aerothermal environment to obtain performance comparisons between AFRSI and ceramic Resuable Surface Insulation (RSI) tiles.

The samples were exposed to a Mach 3.4 flow with a wedge static pressure of 0.74 psia and a computed recovery temperature of 1982°R. These conditions were obtained by inclining the wedge 25 deg to the tunnel Mach 10 flow with a stagnation pressure of 1200 psia and total temperature of 2150°R.

Inquiries to obtain copies of the test data should be directed to Mr. Bill Mosely, ES3, NASA-JSC, Houston, Tx, 77058. A microfilm record has been retained in the VKF at AEDC.

## 2.0 APPARATUS

### 2.1 TEST FACILITY

Tunnel C (Fig. 1) is a closed-circuit, hypersonic wind tunnel with a Mach number 10 axisymmetric contoured nozzle and a 50-in.-diam test section. The tunnel can be operated continuously over a range of pressure levels from 200 to 2000 psia with air supplied by the VKF main compressor plant. Stagnation temperatures sufficient to avoid air liquefaction in the test section (up to 2260°R) are obtained through the use of a natural gas fired combustion heater in series with an electric resistance heater. The entire tunnel (throat, nozzle, test section, and diffuser) is cooled by integral, external water jackets. The tunnel is equipped with a model injection system, which allows removal of the model from the test section while the tunnel remains in operation. A description of the tunnel may be found in the Test Facilities Handbook (Ref. 1).

### 2.2 TEST ARTICLE

Four (4) test articles were furnished by NASA/Ames, photographs of which are presented in Fig. 2. These articles, or samples, were fabricated at NASA/Ames and consisted of various combinations of flexible

reusable surface insulation (FRSI) and ceramic reusable surface insulation (RSI). Shown in Fig. 3 are planform sketches of the test articles denoting the different combinations of insulation used on each sample. Variations among the FRSI samples were the weight of the fabric, the weave of the quilting, and the edge formation. The RSI samples were of different thicknesses and had various silicon coatings applied to their surfaces. The specifics of these variations are beyond the scope of this report, but may be obtained by inquiries directed to the NASA-ARC personnel.

All samples were bonded to an 1/8-in. aluminum plate which in turn was attached to a Bakelite plate of variable thickness to maintain a total thickness of 1.50-in. Presented in Fig. 4 are an installation photograph and sketch of a sample mounted on a steel wedge designed for materials testing. Three rows of steel balls (0.078-in. diam) were welded to the steel surface 3-in. aft of its leading edge to produce a turbulent boundary-layer over the samples. From prior testing with this wedge, it is known that a turbulent boundary-layer exists ahead of the sample at wedge angles of 12 deg or greater.

## 2.3 TEST INSTRUMENTATION

### 2.3.1 Test Conditions

Tunnel C stilling chamber pressure is measured with a 500- or 2500-psid transducer referenced to a near vacuum. Based on periodic comparisons with secondary standards, the accuracy (a bandwidth which includes 95-percent of the residuals, i.e. 2 $\sigma$  deviation) of the transducers is estimated to be within  $\pm 0.16$  percent of pressure or  $\pm 0.5$  psi, whichever is greater, for the 500-psid range and  $\pm 0.16$  percent of pressure or  $\pm 2.0$  psi, whichever is greater, for the 2500-psid range. Stilling chamber temperature measurements are made with Chromel-Alumel thermocouples which have an uncertainty of  $\pm (1.5^\circ\text{F} + 0.375 \text{ percent of reading in } ^\circ\text{F})$ .

### 2.3.2 Test Data

The sample instrumentation consisted of thermocouples (22 in samples 1, 3, and 4; 23 in sample 2) placed at positions of interest to evaluate the thermal response. The thermocouples were of AWG #36 (0.005 in. diam) platinum/platinum-rhodium (13%) material. The placement of these thermocouples in the samples are shown in Fig. 5. The precision of these thermocouple measurements is  $\pm 3$  to 4 deg from room temperature to 1200°F.

Also a user-supplied radiometer was set up to view a 0.5-in. diam area of the sample surface about 2.8-in. back of the sample leading edge and on the wedge centerline. This instrument recorded the total radiant heat flux emitted from the sample area and its output was recorded in millivolts. The precision of the recorded signal is estimated to be  $\pm 0.015$  millivolts.

The VKF infrared system was used to map the sample surface temperature. The system utilizes an AGA Thermovision 680 camera which scans at a rate of 16 frames per second. The camera detector is sensitive to infrared radiation in the 2 to 6 micron wavelength band. Camera calibrations are performed with a standard black body reference

source and have consistently been within  $\pm 1$  percent of the camera manufacturer's calibration and are repeatable within  $\pm 1$  percent in absolute temperature. A description of the VKF system is given in Ref. 2.

The output of the IR camera was displayed on a color TV monitor in real time and at selected times the monitor was photographed with a 70mm color still camera.

Sixteen mm color movies were taken of the samples intermittently during the run and shadowgraphs were taken after the samples reached the tunnel centerline and at selected wedge angles to record the flowfield characteristics.

### 3.0 TEST DESCRIPTION

#### 3.1 TEST CONDITIONS AND PROCEDURES

##### 3.1.1 General

The test was conducted at a nominal Mach number of 10 and the stream conditions were maintained at approximately the values listed below.

<u>M</u>	<u>PT, psia</u>	<u>TT, °R</u>	<u>Q, psia</u>	<u>P, psia</u>	<u>RE x 10<sup>-6</sup>/ft</u>	<u>M<sub>w</sub></u>	<u>P<sub>w</sub>, psia</u>	<u>TAW<sub>w</sub>, °R</u>
10.14	1200	2150	1.75	0.024	1.18	3.4	0.74	1982.0

A test summary showing all configurations tested and the variables for each is presented in Table 1.

In the VKF continuous flow wind tunnels (A, B, C), the model is mounted on a sting support mechanism in an installation tank directly underneath the tunnel test section. The tank is separated from the tunnel by a pair of fairing doors and a safety door. When closed, the fairing doors, except for a slot for the pitch sector, cover the opening to the tank and the safety door seals the tunnel from the tank area. After the model is prepared for a data run, the personnel access door to the installation tank is closed, the tank is vented to the tunnel flow, the safety and fairing doors are opened, and the model is injected into the airstream, and the fairing doors are closed. After the data are obtained, the model is retracted into the tank and the sequence is reversed with the tank being vented to atmosphere to allow access to the model in preparation for the next run. The sequence is repeated for each configuration change.

##### 3.1.2 Data Acquisition

The procedure for obtaining the test measurements changed during the progress of the test. Initially there was concern for the survivability of the cloth samples at wedge angles as large as 25 deg; hence, the wedge was injected at zero pitch and rotated to 25 deg, observing the sample (#3 was used) for any indication of failure, and reversing the procedure for retraction. No indications of failure were observed. Next the sample



was injected and retracted at 25 deg and again observed for indications of failure. No problems were encountered during injection but on retraction the top layer of the cloth sample was blown away (see Fig. 6(a)). It appears the turbulence encountered during retraction through the tunnel wall boundary layer at such a large angle was too severe. A possible explanation of the absence of failure during injection through the same turbulence is that the increased fabric temperature decreased its strength prior to retraction. Consequently, the initial procedure described above was adopted for the remainder of the test.

The samples were exposed to the flow for 10 minutes each time they were injected. The output of all the instrumentation was recorded every 0.5 sec until the wedge reached the 25 deg pitch angle, then data were recorded every 5 sec for the remainder of the run. The IR system TV monitor was observed, and when the sample surface temperature showed approximately 1200°F a 70mm photograph was taken. Another photograph was taken just prior to retraction.

The samples were observed directly during exposure, and whenever any unusual circumstances developed (fabric tears or loose tiles) the 16mm movie camera was used to record the events. In addition, the injection cycle of each run was recorded on 16mm film.

After retraction, the sample was cooled by a tank door nozzle and adjustable mainfolds on each side using high pressure air. Also the sample support wedge has internal water cooling passages which aided in cooling the sample. Whenever the sample aluminum support plate cooled to 150°F, the sample was injected for another run or replaced by another sample. Any damage to the samples was photographed using a 70mm camera prior to continued testing (see Fig. 6(b)).

Each exposure is termed a run and all the data obtained are identified in the data tabulations by run number. The sample tested during each run is listed in Table 1.

### 3.2 DATA REDUCTION

The tabulated data for each run includes a listing of tunnel conditions and sample information necessary to use the data. Beneath this listing the sample temperatures and radiometer output are listed at selected times. The wedge angle is included in this listing to document its variation with time. A description of the computation procedures used to produce the data follows.

#### 3.2.1 IR System Photographs of Sample Surface Temperature

The calibration of the IR system itself is detailed in Ref. 2 and the only other information required to obtain the sample surface temperature is the surface emissivity.

A representative sample of the fabric insulation was examined to determine its emissivity over the range of 3 to 6 microns. The results are presented in Fig. 7. The sample total emissivity was computed by the equation

$$\epsilon = \frac{\int_{\lambda} \epsilon_{\lambda} e_{b\lambda} X_{\lambda} d\lambda}{\int_{\lambda} e_{b\lambda} X_{\lambda} d\lambda} \quad (1)$$

where

$\epsilon_{\lambda}$  = is the sample spectral emissivity from Fig. 7 at 530°R

$e_{b\lambda}$  = is the black body spectral emissivity at 530°R

$X_{\lambda}$  = is the IR camera spectral response factor obtained from AGA data.

Both  $e_{b\lambda}$  and  $e_{b\lambda} * X_{\lambda}$  variations with wavelength over the range of interest are presented in Fig. 8(a) and  $\epsilon_{\lambda} * e_{b\lambda} * X_{\lambda}$  variations are shown in Fig. 8(b). The values of the integrals are shown in the figures; from these the sample total emissivity was computed to be 0.62. For this emissivity, the color calibration with temperature for the photographs off the IR system TV monitor is listed in Table 2.

### 3.2.2 Sample Temperatures

Because the VKF thermocouple hookup network does not include provisions for platinum/platinum-rhodium (13%) thermocouples and the expense of platinum wire, the thermocouple leads were only about 12-in. long and terminated at a 50-pin connector inside the wedge support. Copper leads were used from the other side of the connector to the instrumentation. The output of the sample thermocouples was dependent upon the connector temperature with this type hookup; hence, two positions on the connector were used to measure the connector (reference) temperature using Chromel®-Alumel® thermocouple wire. The reference temperatures were measured with direct-readout instruments in °F.

The total output of each sample thermocouple was computed by first calculating the equivalent platinum millivolt output of the reference thermocouple using the following equation

$$E_R = 0.42282 + (2.66830 \times 10^{-3}) TR1 + (4.49139 \times 10^{-6}) (TR1)^2 - (3.50748 \times 10^{-9}) (TR1)^3 + (1.40615 \times 10^{-12}) (TR1)^4 \quad (2)$$

where

$E_R$  = equivalent millivolt output of a platinum thermocouple at temperature TR1

TR1 = measured reference temperature in °F

A second reference temperature (TR2) was used as a redundant measurement. The reference millivolts ( $E_R$ ) were added to the output of each platinum thermocouple ( $E_M$ ) to obtain the total millivolts output of each thermocouple ( $E_{TC}$ ). The temperature for each platinum thermocouple was then computed from the equation

$$TC1 = A0 + A1(E_{TC1}) + A2(E_{TC1})^2 + \dots + AN(E_{TC1})^N \quad (3)$$

where the coefficients A0, ..., AN are determined from the following table

Range of $E_{TC1}$ , mv	A0	A1	A2	A3	A4	A5
$-0.422 \leq E_{TC1} \leq 1.175$	591.727	270.981	-11.8644	53.7323	-37.7430	11.9930
$1.175 \leq E_{TC1} \leq 5.604$	605.398	234.610	-17.7323	2.18924	-0.122826	--
$5.604 \leq E_{TC1} \leq 11.024$	657.117	192.452	-3.8197	0.0687992	--	--

and i denotes the TC number.

The connector reference temperatures (TR1 and TR2) as well as the output of the Ames radiometer were printed out as measured.

### 3.3 UNCERTAINTY OF MEASUREMENTS

#### 3.3.1 General

The accuracy of the basic measurements (PT and TT) was discussed in Section 2.3. Based on repeat calibrations, these errors were found to be

$$\frac{\Delta PT}{PT} = 0.0016 = 0.16\%, \quad \frac{\Delta TT}{TT} = 0.004 = 0.4\%$$

Uncertainties in the tunnel free-stream parameters and the model temperatures were estimated using the Taylor series method of error propagation, Eq. (4),

$$(\Delta F)^2 = \left( \frac{\partial F}{\partial X_1} \Delta X_1 \right)^2 + \left( \frac{\partial F}{\partial X_2} \Delta X_2 \right)^2 + \left( \frac{\partial F}{\partial X_3} \Delta X_3 \right)^2 + \dots + \left( \frac{\partial F}{\partial X_n} \Delta X_n \right)^2 \quad (4)$$

where  $\Delta F$  is the absolute uncertainty in the dependent parameter  $F = f(X_1, X_2, X_3, \dots, X_n)$  and  $X_n$  are the independent parameters (or basic measurements).  $\Delta X_n$  are the uncertainties (errors) in the independent measurements (or variables).

### 3.3.2 Test Conditions

The accuracy (based on  $2\sigma$  deviation) of the basic tunnel parameters, PT and TT, (see Section 2.3) and the  $2\sigma$  deviation in Mach number determined from test section flow calibrations were used to estimate uncertainties in the other free-stream properties using Eq. (1). The computed uncertainties in the tunnel free-stream conditions are summarized in the following table.

<u>Uncertainty, (<math>\pm</math>) percent of actual value</u>				
<u>M</u>	<u>M</u>	<u>P</u>	<u>Q</u>	<u>RE</u>
10.14	1.0	5.3	3.7	2.3

The uncertainty of the wedge angle is estimated to be  $\pm 0.1$  deg.

### 3.3.3 Test Data

The uncertainties of the test data parameters are summarized in the following table

<u>Data Type</u>	<u>Uncertainty, (<math>\pm</math>) percent of actual value</u>
IR Color Interface Temperature	1.00
Ames Radiometer Output	0.14
Sample Temperature @ 1560°R	0.35
Reference Temperature @ 575°R	0.67

## 4.0 DATA PACKAGE PRESENTATION

Tabulated results and plotted data were furnished to the test sponsor in a Data Package. Samples of these data are presented in Appendix III.

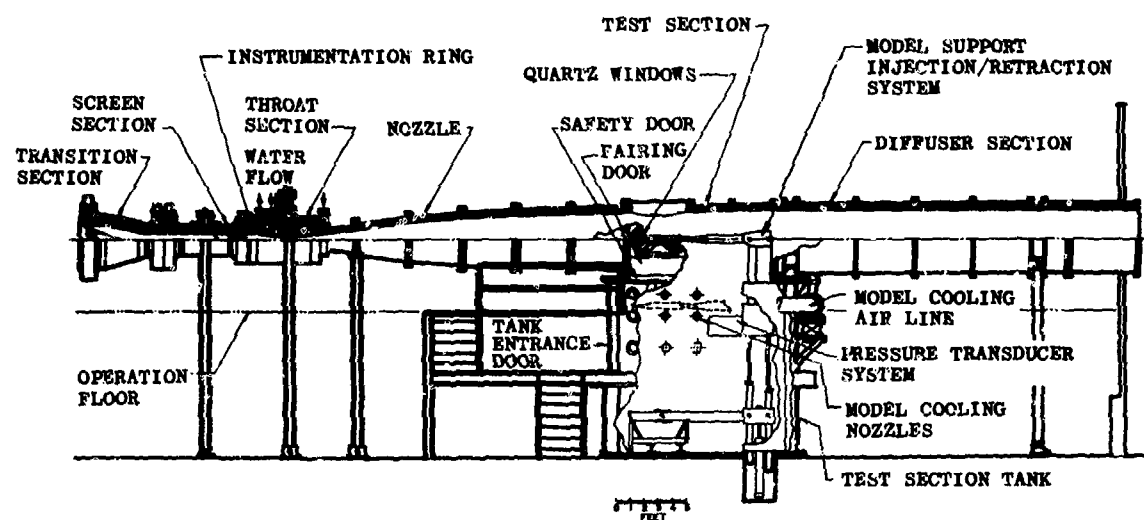
Some of the sample temperature variations with time shown in the plots are due to the wedge angle variations with time. Therefore, as an aid to the interpretation of the plots shown herein, the wedge angle variation for run 26 is included with the data plots. The wedge angle variations for each run are listed on the tabulated data.

#### REFERENCES

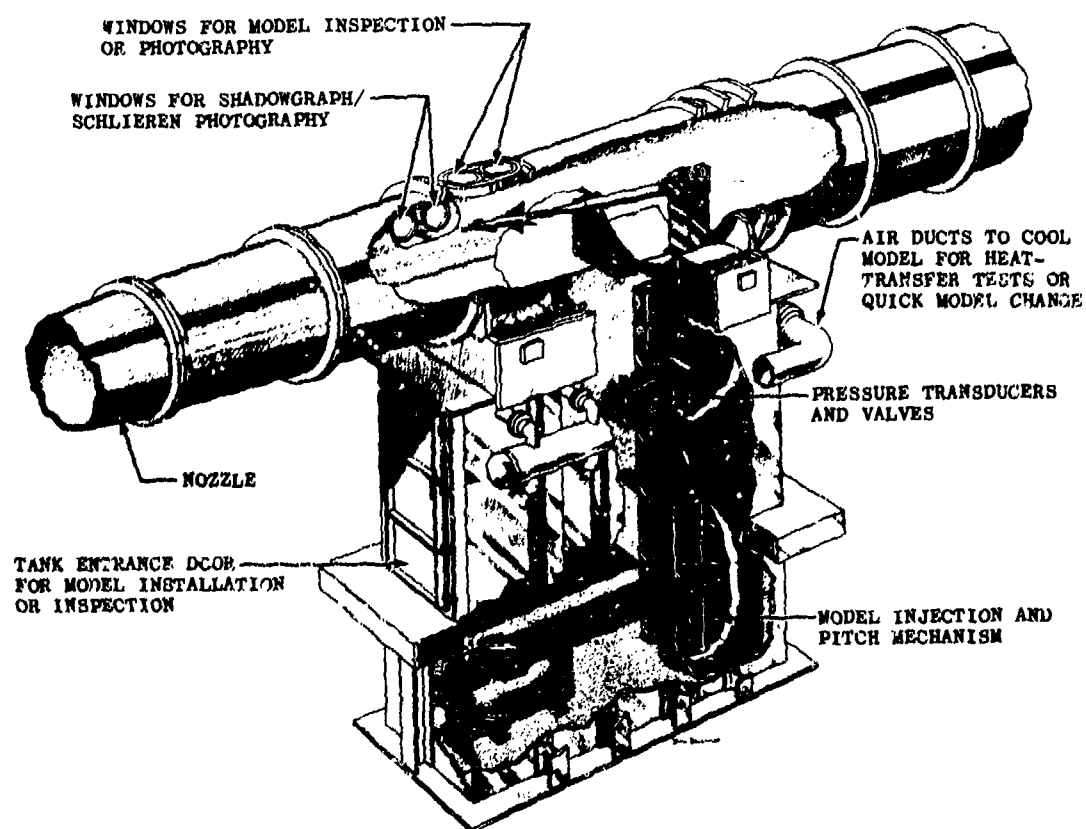
1. Test Facilities Handbook (Tenth Edition). "von Karman Gas Dynamics Facility, Vol. 3" Arnold Engineering Development Center, May 1974.
2. Boylan, D. E, et al, "Measurements and Mapping of Aerodynamic Heating Using a Remote Scanning Camera in Continuous Flow Wind Tunnels," AIAA Paper 78-799, April 1978.

APPENDIX I

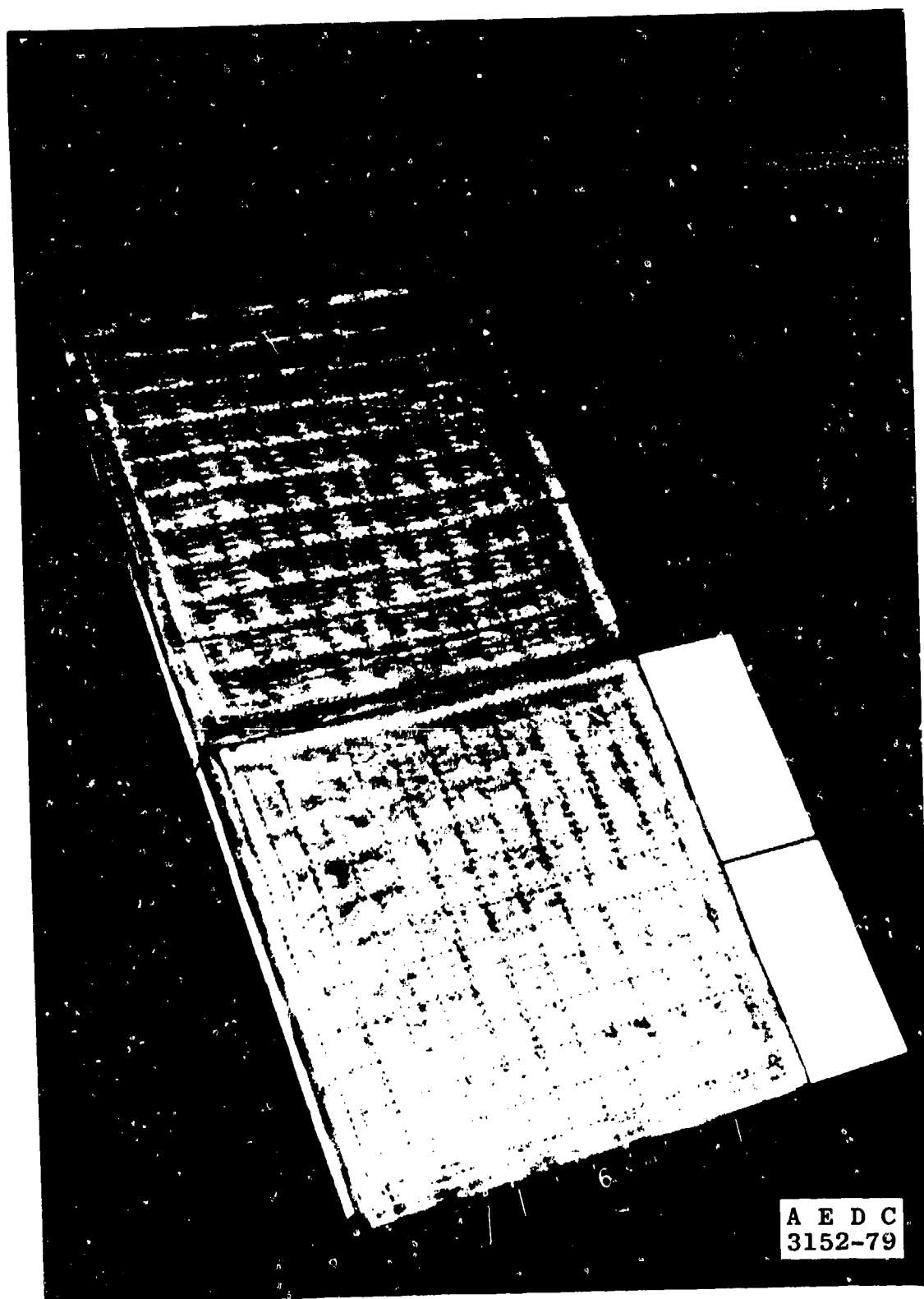
ILLUSTRATIONS



a. Tunnel assembly

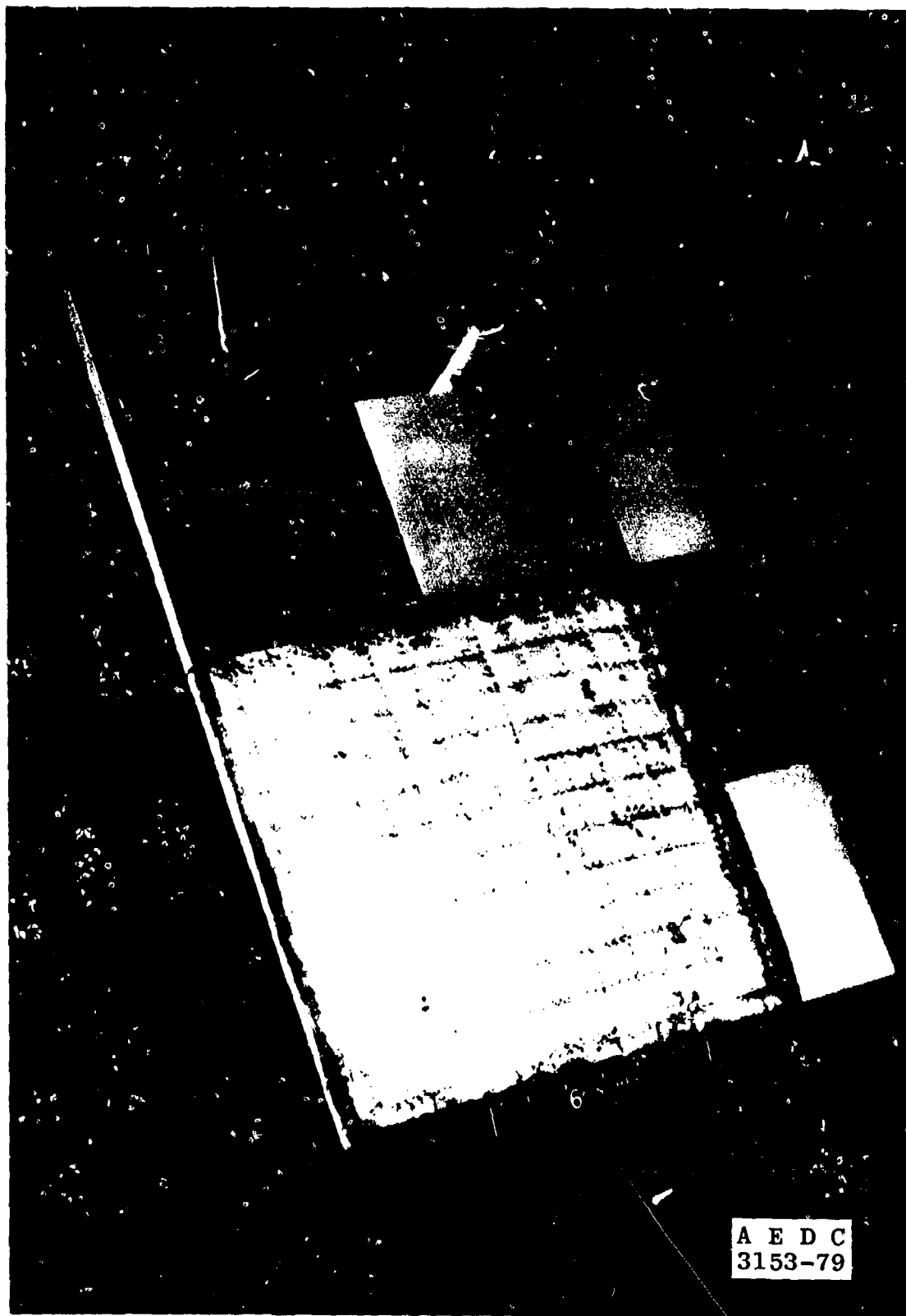


b. Tunnel test section  
Fig. 1 Tunnel C

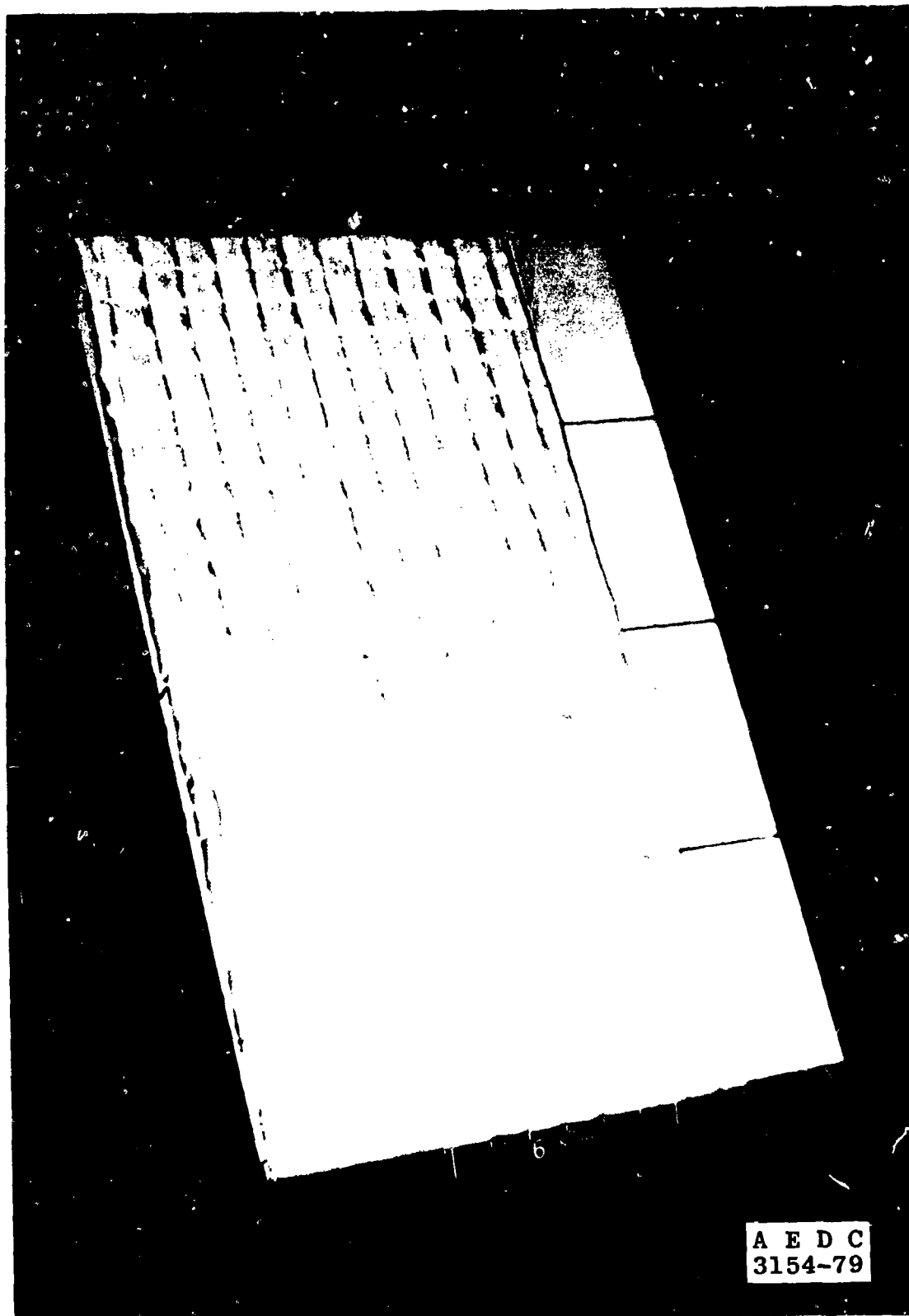


a. No. 1  
Fig. 2 Sample Photographs

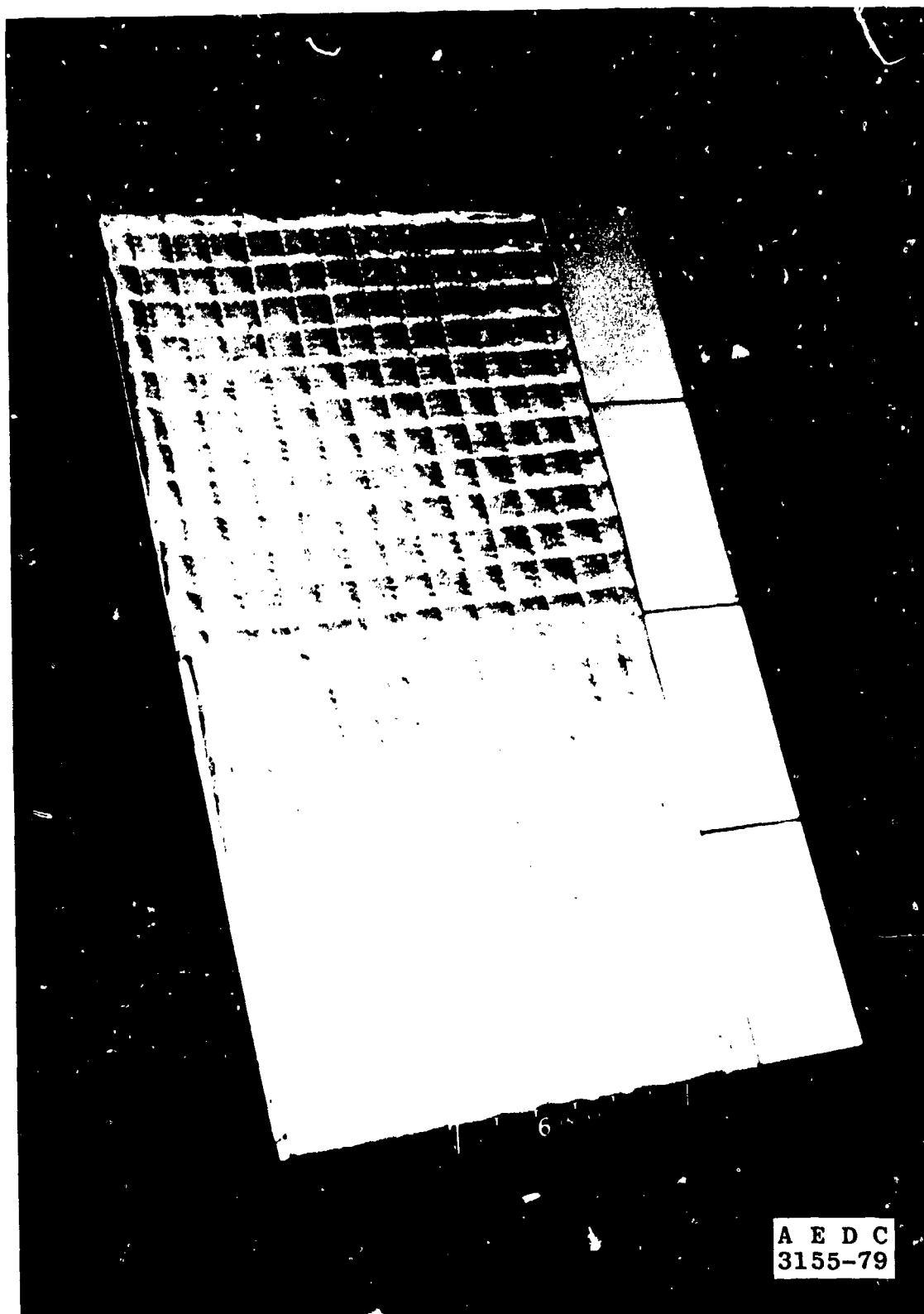




b. No. 2  
Fig. 2 Continued

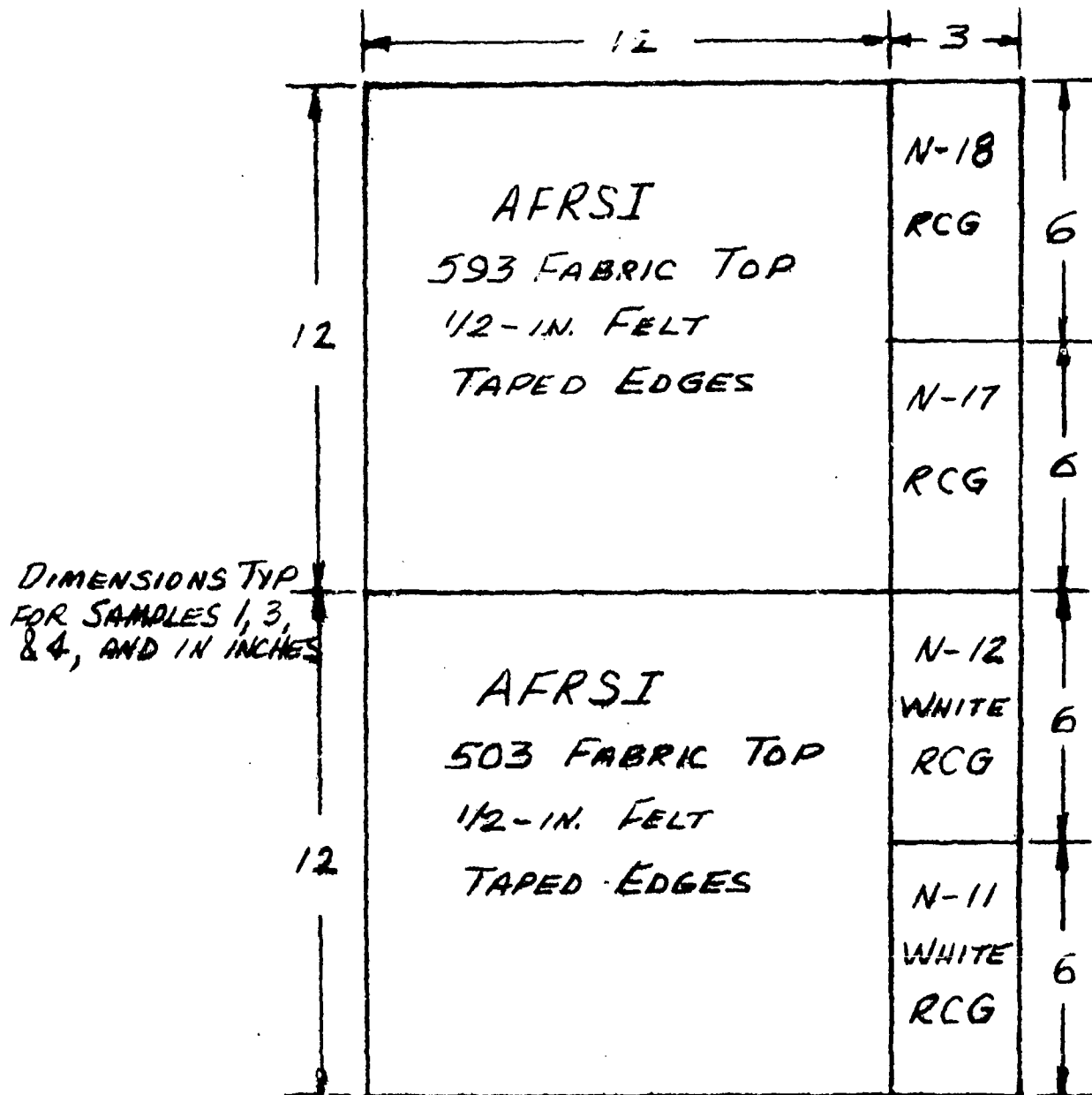


c. No. 3  
Fig. 2 Continued



d. No. 4  
Fig. 2 Concluded

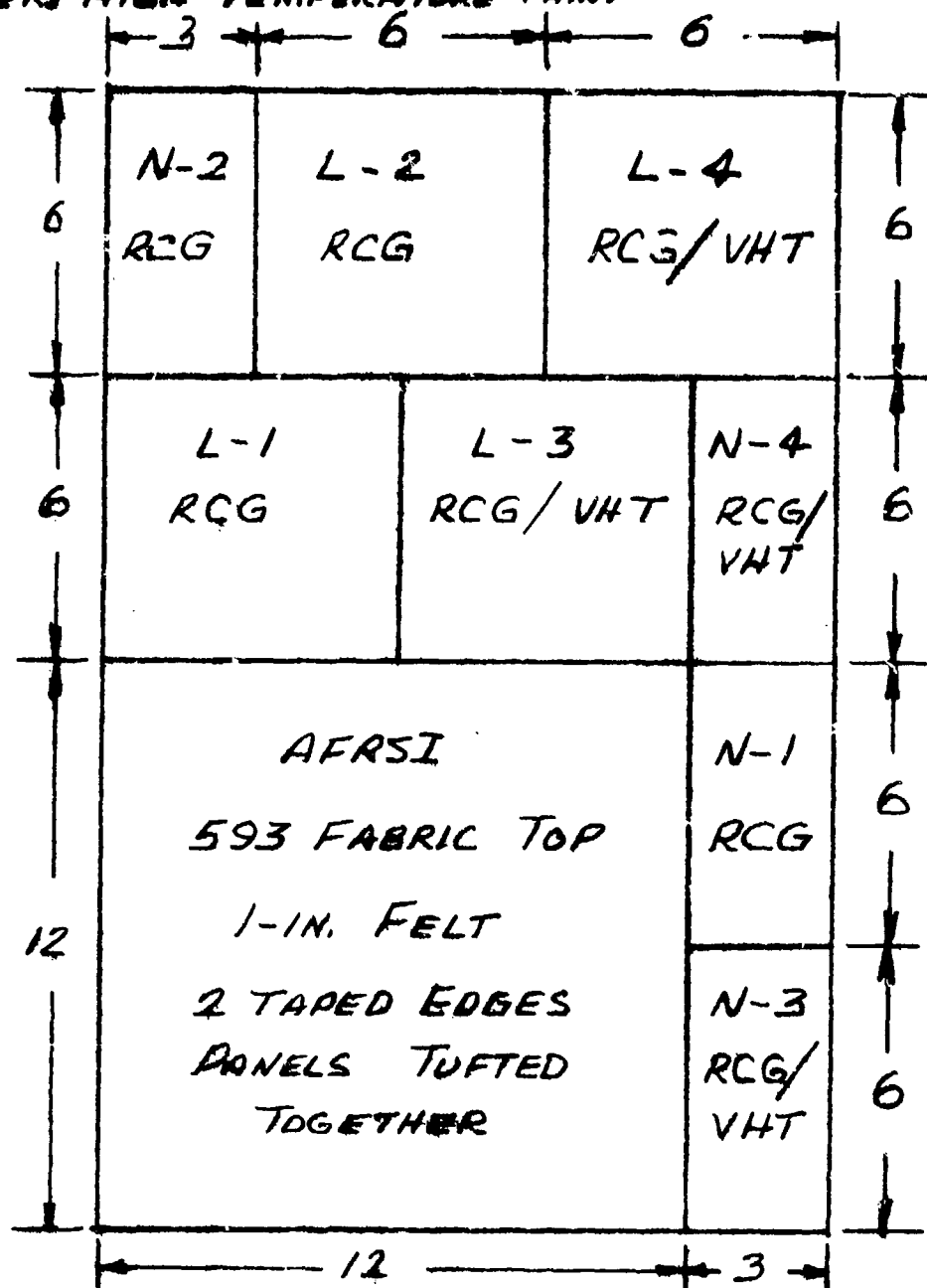
AFRSI = ADVANCED FLEXIBLE REUSABLE SURFACE INSULATION  
 RCG = REACTION CURED GLASS



(a) No. 1

Fig. 3 Sample Details

AFRSI = ADVANCED FLEXIBLE REUSABLE SURFACE INSULATION  
 RCG = REACTION CURED GLASS  
 VHT = VERY HIGH TEMPERATURE PAINT



(b) No. 2

ALL DIMENSIONS IN INCHES

Fig. 3 Continued

AFRSI = ADVANCED FLEXIBLE REUSABLE SURFACE INSULATION  
 RCG = REACTION CURED GLASS  
 VHT = VERY HIGH TEMPERATURE PAINT

AFRSI 593 FABRIC TOP 1/2-IN. FELT ROLLED EDGES	N-20 RCG/ VHT
	N-19 RCG/ VHT
AFRSI 503 FABRIC TOP 1/2-IN. FELT ROLLED EDGES	N-14 WHITE RCG
	N-13 WHITE RCG

(c) No. 3

Fig. 3 Continued

AFRSI = ADVANCED FLEXIBLE REUSABLE SURFACE INSULATION  
 RCG = REACTION CURED GLASS  
 VHT = VERY HIGH TEMPERATURE PAINT

AFRSI 593 FABRIC 1/2-IN. FELT ROLLED EDGES	N-22 RCG/ VHT
	N-21 RCG/ VHT
AFRSI 503 FABRIC 1/2-IN. FELT ROLLED EDGES	N-16 WHITE RCG
	N-15 WHITE RCG

(d) No. 4

Fig. 3 Concluded



Fig. 4 Installation Photograph and Sketches



# TUNNEL WALL

**AFT. C. R.**  
**STA. 29673**

**ROLL NO.**  
**STA. 0.00**

67-2705

CA-30

$C.R = 16$

$$C_R = 0$$

25. MAXIMUM WEDGE ANGLE

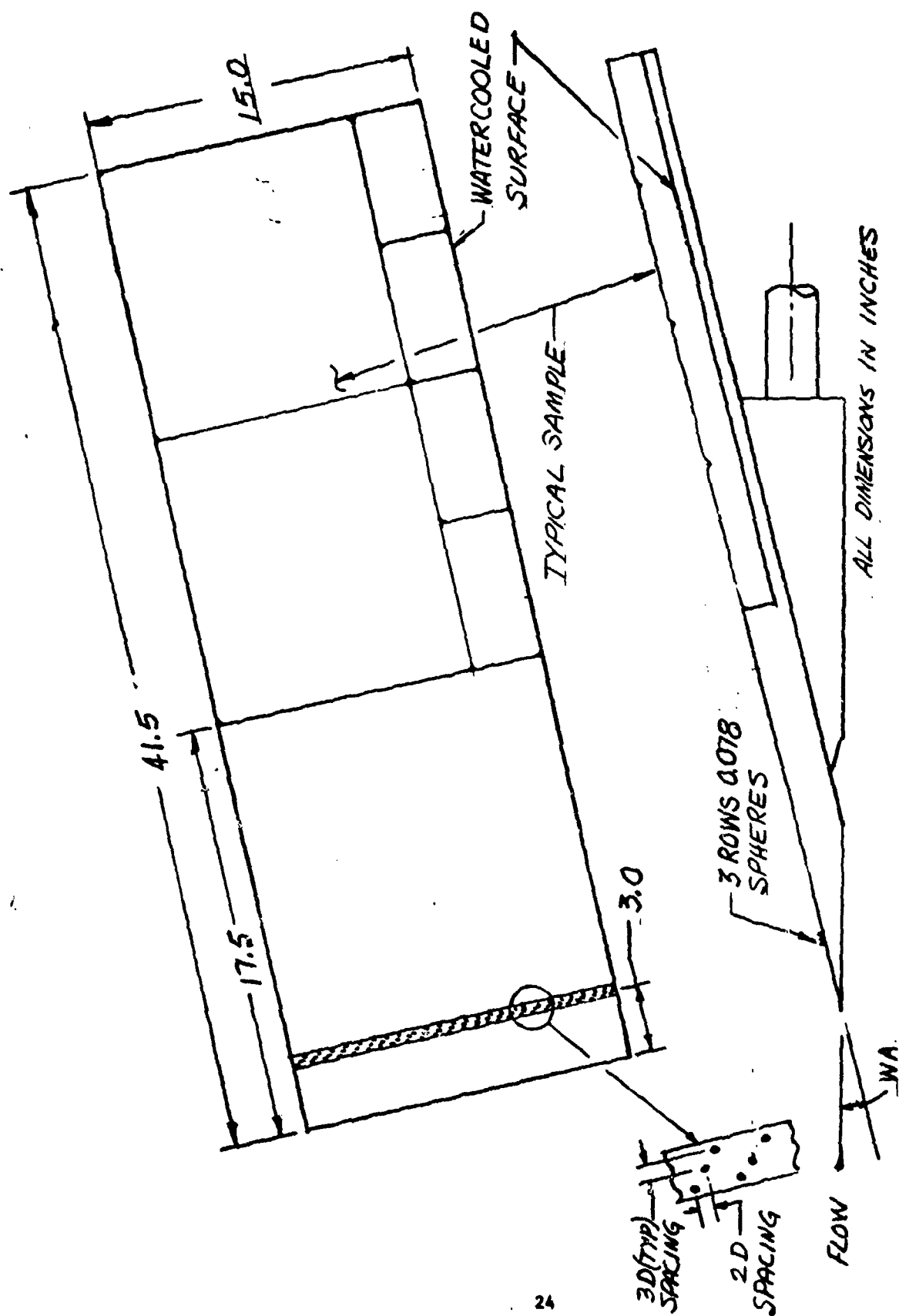
406-2-37-207

12. PREPEND ANGLE

INSTALLATION  
DASB/WEBB  
VGLC-56  
6/14/78

**(b) Installation sketch**

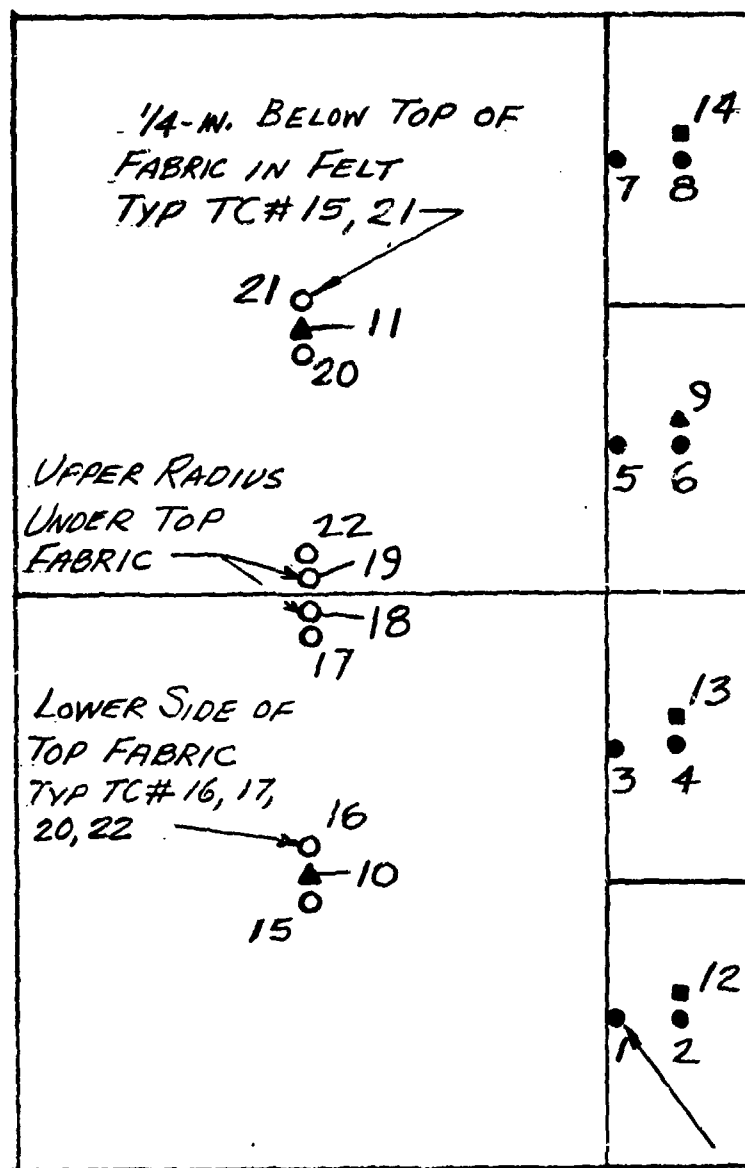
**Fig. 4 Continued** **TUNNEL WALL**



(c) Dimensional sketch

Fig. 4 Concluded

NOTE: THERMOCOUPLE LOCATIONS SHOWN ARE APPROXIMATE

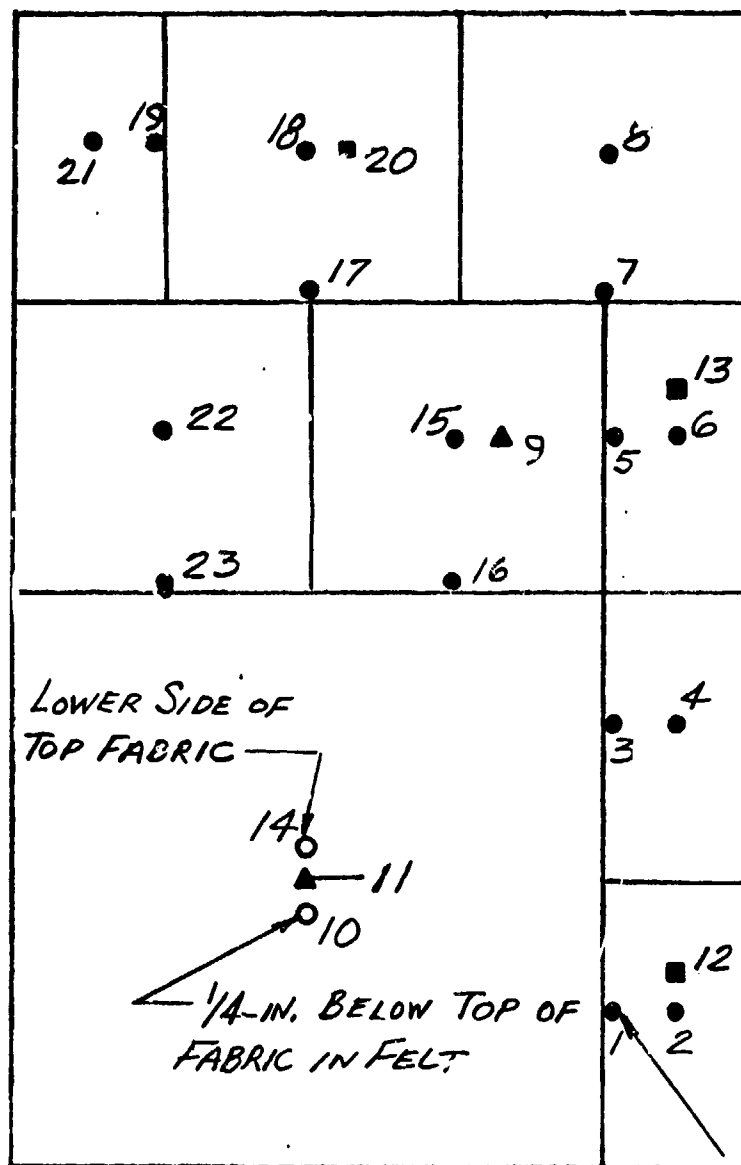


- 1/8-IN. FROM TOP OF RSI TILE
- TOP OF STRAIN ISOLATION PAD
- ▲ TOP OF ALUMINUM SUPPORT PLATE
- AERSI PANEL (LOCATION NOTED)

(a) Samples 1, 3, and 4

Fig. 5 Sample Thermocouple Locations

NOTE: THERMOCOUPLE LOCATIONS SHOWN ARE APPROXIMATE.



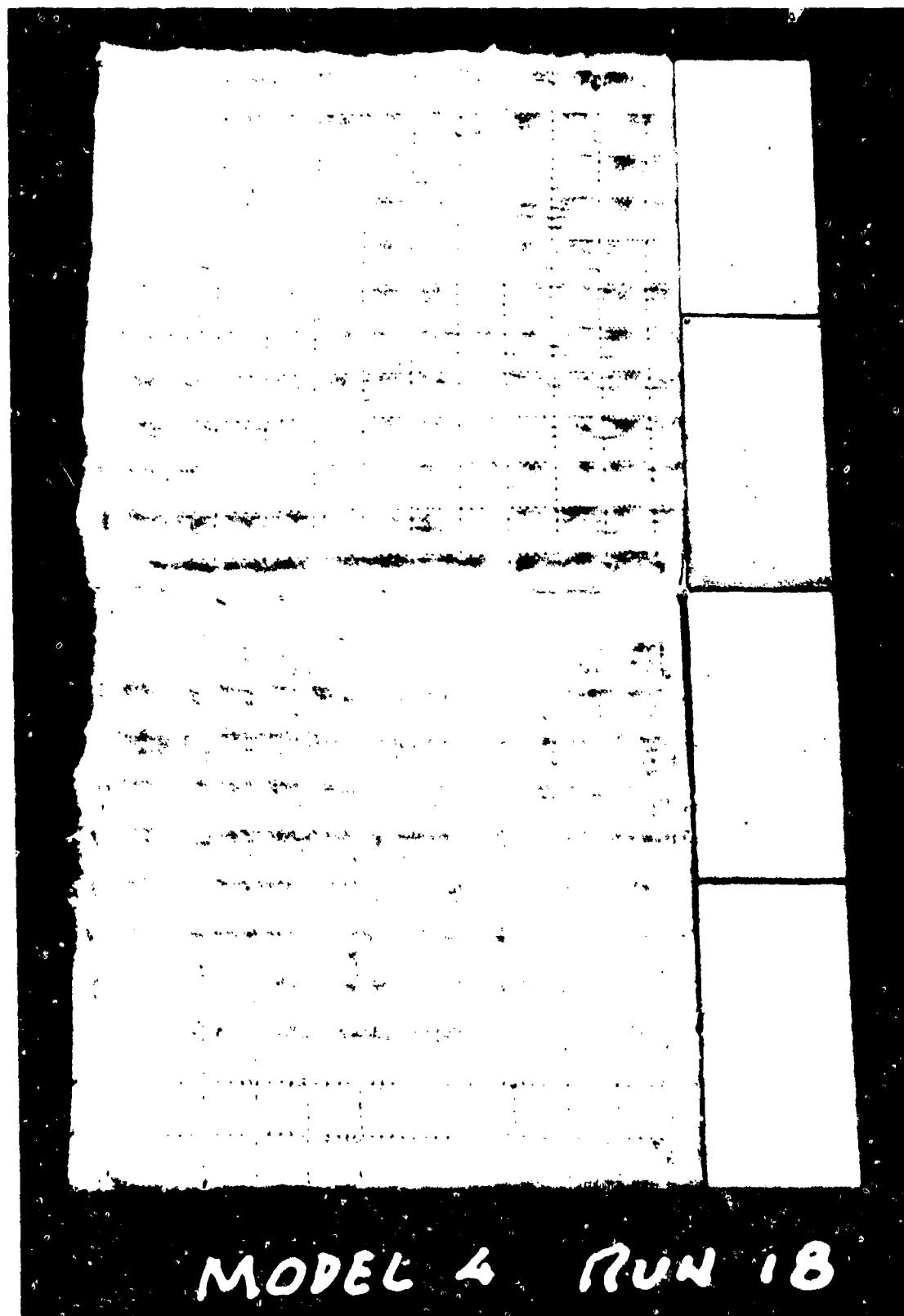
- 1/8-IN. FROM TOP OF RSI TILE
- TOP OF STRAIN ISOLATION PAD
- ▲ TOP OF ALUMINUM SUPPORT PLATE
- AFRSI PANEL (LOCATION NOTED)

(b) Sample 2

Fig. 5 Concluded



a. Sample 3 after Run 1  
Fig. 6 Photographs of Damaged Samples



b. Sample 4 after Run 18  
Fig. 6 Concluded

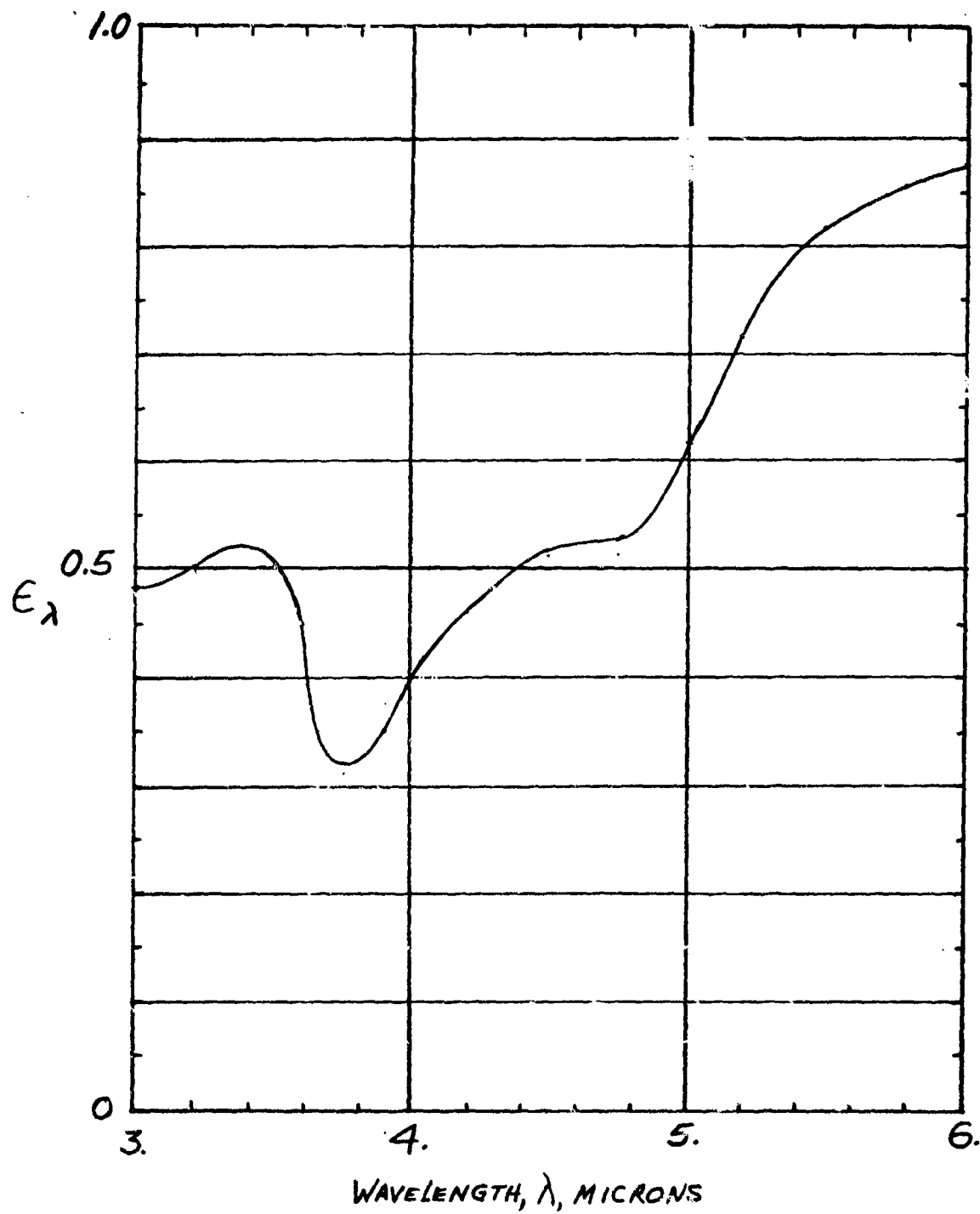
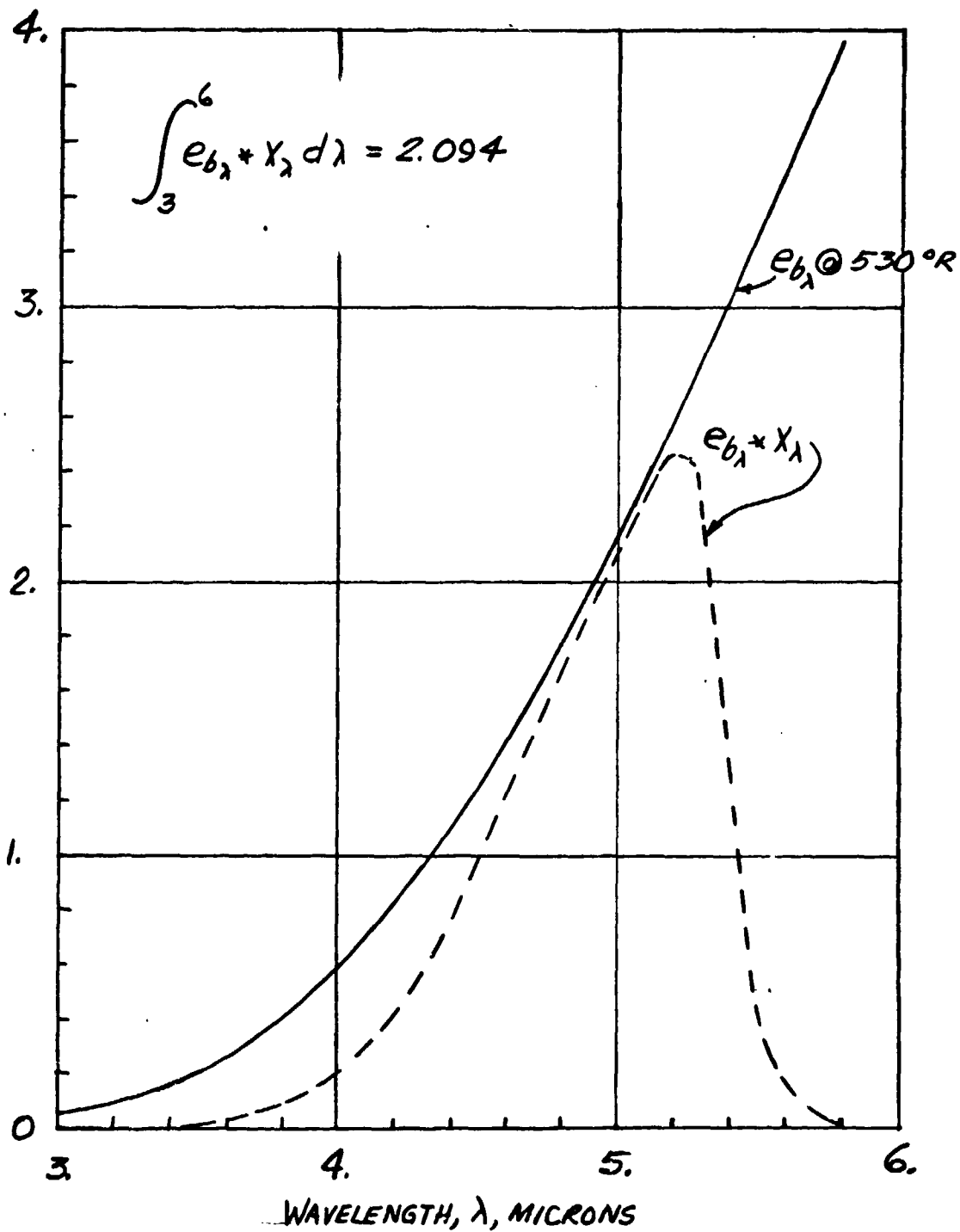


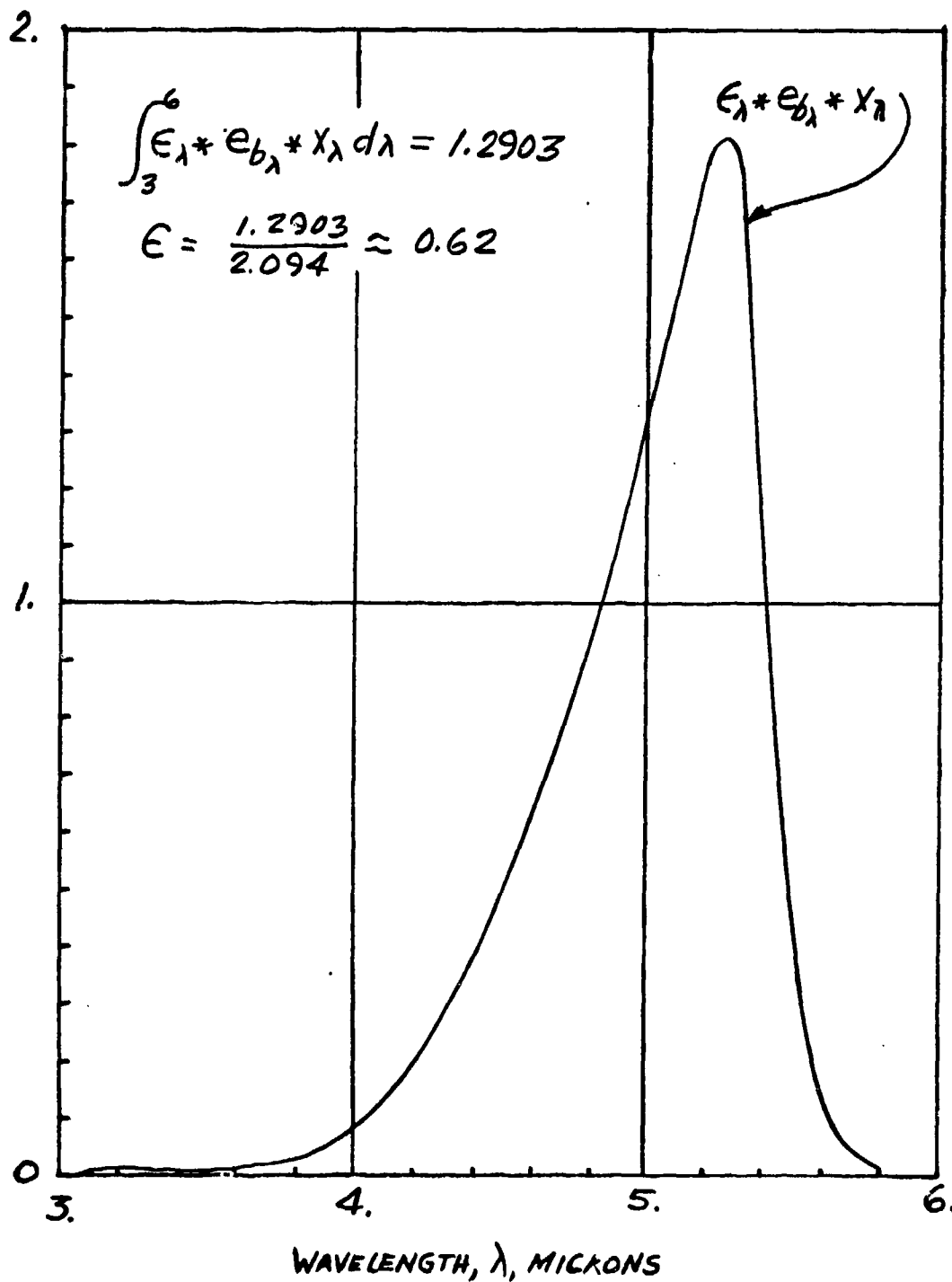
Fig. 7 Sample AFRSI Spectral Emissivity



(a) Black body emissivity and IR camera response factor

Fig. 8 Black Body and AFRSI Total Emissivity





(b) AFRSI sample total emissivity

Fig. 8 Concluded

**APPENDIX II**

**v**

**TABLES**

TABLE 1

TEST SUMMARY

SAMPLE NUMBER	SAMPLE POSITION, DEG	RUN
1	0	2, 3, 4
2	0	9, 10, 11, 12, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29
3	180	7
4	0	5, 6, 7, 8, 13, 14, 15, 16, 17, 18

TABLE 2

## IR SYSTEM COLOR/TEMPERATURE CALIBRATION

IR CAMERA	RUN 1	RUNS 2 - 29
SENSITIVITY	500	200
BLACK LEVEL	0.097	1.216
COLOR NUMBER	TEMPERATURE AT COLOR LOWER LIMIT, °R	
1	-	1459
2	-	1503
3	754	1544
4	1119	1584
5	1289	1622
6	1418	1658
7	1527	1694
8	1623	1728
9	1712	1762
10	1794	1794

## APPENDIX III

### SAMPLE DATA

1. Tabulated Data
2. Plotted Data
3. IR System Photograph

DATE COMPUTED 4-MAY-79  
 TIME COMPUTED 14148128  
 DATE RECORDED 6-APR-79  
 TIME RECORDED 4110: 7  
 PROJECT NUMBER V41C-56

PAGE 1

50 INCH HYPERSONIC TUNNEL, C

APO, TX - AEDC DIVISION  
 A SVERDRUP CORPORATION COMPANY  
 VON KARMAN GAS DYNAMICS FACILITY  
 ARNOLD AIR FORCE STATION, TENNESSEE  
 NASA/AMES APTSI MATERIALS TEST

CR  
(INCHES)  
25.00

RUN	CONFIG	SAMPLE	M	PT-PSIA	TT-DEG R	ALPI (DEG)	PHII (DEG)
26	2	0	10.14	1194.90	2142.7	11.60	199.88

TIMEEXP (SEC)  
 105.7  
 0.024  
 1.73  
 5109.8  
 6.172E-04  
 1.193E+09  
 5.457E+02  
 6.01  
 4  
 10  
 35  
 232  
 680.26

WEDGE ATTITUDE AND TEMPERATURE HISTORY

TIMEEXP (SEC)	WA (DEG)	TC1 (DEG R)	TC2 (DEG R)	TC3 (DEG R)	TC4 (DEG R)	TC5 (DEG R)	TC6 (DEG R)	TC7 (DEG R)	TC8 (DEG R)	TC9 (DEG R)	TC10 (DEG R)	TC11 (DEG R)	TC12 (DEG R)
1.1	0.36	541.	547.	552.	546.	545.	545.	545.	534.	597.	597.	601.	601.
2.1	0.42	554.	552.	558.	553.	548.	573.	547.	540.	597.	597.	601.	601.
3.1	0.40	559.	554.	566.	557.	551.	582.	553.	544.	597.	597.	601.	601.
4.1	0.40	564.	559.	572.	567.	553.	589.	560.	549.	597.	597.	601.	601.
5.1	0.40	569.	564.	580.	567.	557.	593.	566.	553.	597.	597.	601.	601.
6.1	0.39	574.	567.	586.	570.	561.	601.	573.	559.	597.	597.	601.	601.
7.1	0.38	578.	571.	592.	575.	564.	606.	579.	562.	597.	597.	601.	601.
8.1	0.38	582.	575.	599.	579.	567.	610.	584.	568.	597.	597.	601.	601.
9.1	0.39	587.	578.	604.	584.	570.	617.	590.	573.	597.	597.	601.	601.
10.1	0.39	591.	582.	609.	588.	574.	622.	597.	576.	597.	597.	601.	601.
15.1	0.39	608.	600.	634.	607.	588.	644.	670.	598.	598.	598.	599.	599.
20.1	0.39	623.	616.	655.	625.	602.	664.	638.	618.	596.	596.	599.	599.
30.1	6.40	685.	663.	758.	682.	655.	741.	833.	685.	596.	596.	599.	599.
40.1	6.40	675.	781.	1049.	659.	912.	958.	1104.	843.	596.	596.	599.	599.
50.1	14.18	1137.	942.	1178.	1019.	1107.	1099.	1269.	975.	601.	601.	597.	597.
60.1	24.26	1412.	1151.	1297.	1202.	1316.	1281.	1539.	1137.	620.	620.	596.	596.
71.3	24.53	1494.	1226.	1360.	1278.	1393.	1356.	1578.	1211.	641.	641.	595.	595.
81.3	24.52	1530.	1278.	1416.	1328.	1445.	1396.	1594.	1266.	683.	683.	595.	595.
90.7	24.51	1544.	1303.	1445.	1351.	1469.	1414.	1602.	1292.	728.	728.	595.	595.
101.3	24.40	1550.	1319.	1462.	1365.	1483.	1422.	1605.	1311.	771.	771.	595.	595.
CAMERA NO. 1, TAPES AT 121.3 SECONDS													
121.3	24.47	1558.	1339.	1480.	1381.	1496.	1435.	1610.	1333.	840.	840.	593.	593.
151.3	24.47	1565.	1358.	1495.	1397.	1506.	1446.	1614.	1353.	918.	918.	593.	593.
201.2	24.45	1570.	1378.	1508.	1413.	1512.	1456.	1616.	1371.	1008.	1008.	593.	593.
301.3	24.44	1573.	1402.	1519.	1429.	1513.	1468.	1618.	1388.	1109.	1109.	605.	605.
401.2	24.43	1577.	1417.	1528.	1438.	1513.	1474.	1620.	1397.	1165.	1165.	622.	622.
501.2	24.42	1577.	1422.	1531.	1441.	1511.	1476.	1617.	1400.	1197.	1197.	639.	639.
601.2	24.40	1578.	1426.	1534.	1444.	1512.	1479.	1615.	1402.	1217.	1217.	654.	654.

ARO, INC. - AERO DIVISION  
A SYNERGIC CORPORATION COMPANY  
VON KARMAN GAS DYNAMICS FACILITY  
AROLD AIR FORCE STATION, TENNESSEE  
NASA/AMES APTSI MATERIALS TEST

DATE COMPUTED 4-MAY-79  
TIME COMPUTED 14:48:29  
DATE RECORDED 6-APR-79  
TIME RECORDED 4:10:17  
PROJECT NUMBER V41C-86

PAGE 2

# 50 INCH HYPERSONIC TUNNEL C

CR  
(INCHES)  
25.00

PHIL  
(DEG)  
190.88

ALPI  
(DEG)  
11.60

TT, DEG R  
2142.7

PT, PSIA  
1194.90

M  
NUMBER  
2

CONFIC  
NUMBER  
2

SAMPLE  
POSITION  
0

RUN  
NUMBER  
26

TIMEEXPT  
(SEC)  
105.7

(PSIA)  
1.739

(FT/SEC)  
5109.8

(LAN/FT)  
6.172E-04

(LBP-SEC/FT)  
8.503E-08

RE  
(PT-1)  
1.193E+09

ITF  
(BTU/LAM)  
5.457E+02

TIMEINJ  
(SEC)  
6.91

TIMECL  
(HOUR MIN SEC)  
4 10 35

TIMEEXPT  
(SEC)  
680.26

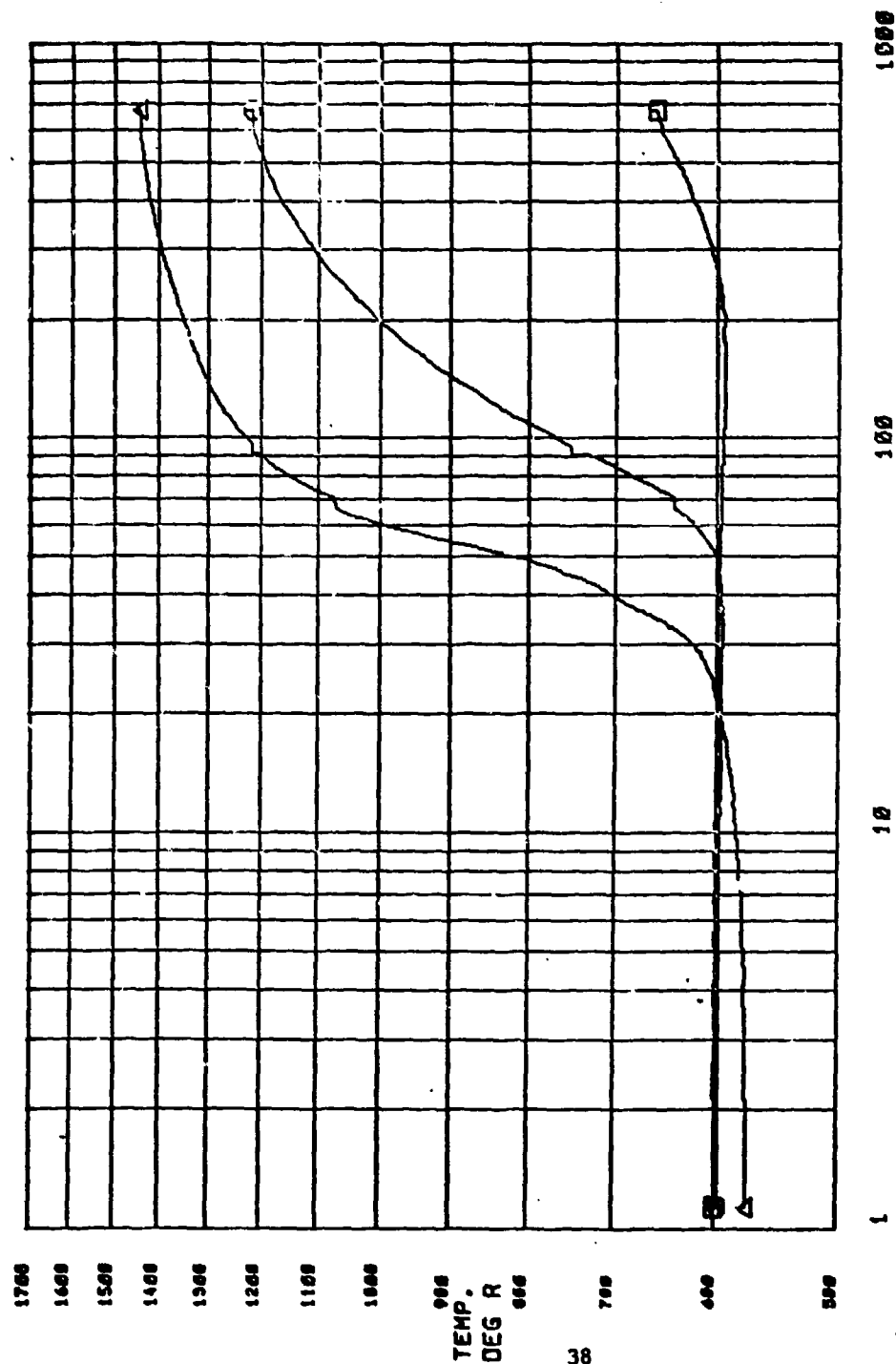
## WEDGE ATTITUDE AND TEMPERATURE HISTORY

TIMEEXP	WA	TC13	TC14	TC15	TC16	TC17	TC18	TC19	TC20	TC21	TC22	TC23	TR1	TR2	AMES SENSOR (MV)
1.1	0.36	595.	572.	574.	530.	534.	536.	542.	593.	546.	546.	565.	592.	591.	0.008
7.1	0.42	595.	573.	539.	538.	540.	543.	549.	593.	562.	562.	571.	592.	590.	0.005
3.1	0.40	595.	573.	544.	543.	549.	550.	556.	593.	568.	568.	571.	592.	590.	0.095
4.1	0.40	595.	573.	549.	550.	558.	559.	564.	594.	575.	575.	582.	592.	590.	0.138
5.1	0.40	595.	576.	556.	558.	568.	567.	571.	593.	582.	582.	590.	592.	590.	0.170
6.1	0.38	595.	576.	560.	564.	576.	577.	580.	594.	589.	589.	597.	592.	590.	0.210
7.1	0.39	594.	578.	566.	570.	584.	585.	586.	593.	594.	597.	604.	592.	590.	0.245
8.1	0.39	595.	579.	572.	577.	593.	594.	593.	593.	600.	601.	610.	592.	590.	0.265
9.1	0.39	595.	580.	577.	582.	599.	602.	599.	593.	605.	608.	616.	592.	590.	0.318
10.1	0.39	594.	582.	582.	589.	607.	610.	605.	593.	610.	615.	622.	592.	590.	0.315
15.1	0.39	593.	589.	607.	614.	635.	645.	632.	592.	635.	642.	647.	591.	590.	0.470
20.1	0.39	593.	597.	630.	636.	660.	674.	654.	591.	656.	666.	669.	591.	590.	0.575
30.1	6.40	592.	622.	718.	746.	839.	783.	793.	591.	722.	745.	776.	591.	590.	1.065
40.1	6.96	592.	704.	920.	1042.	1088.	1094.	1094.	590.	873.	961.	1103.	591.	590.	4.210
50.1	14.18	591.	816.	1085.	1248.	1379.	1098.	1259.	589.	1008.	1101.	1294.	591.	589.	5.920
60.1	24.26	591.	940.	1235.	1478.	1577.	1273.	1432.	587.	1172.	1274.	1533.	590.	589.	8.520
71.3	24.53	589.	1077.	1297.	1542.	1618.	1335.	1491.	587.	1247.	1336.	1587.	590.	589.	9.815
81.3	24.52	590.	1154.	1337.	1574.	1633.	1371.	1526.	587.	1301.	1374.	1612.	590.	589.	9.900
90.7	24.51	591.	1202.	1357.	1587.	1640.	1388.	1540.	586.	1326.	1390.	1623.	590.	589.	10.075
101.3	24.49	592.	1215.	1370.	1596.	1644.	1398.	1547.	586.	1341.	1399.	1630.	590.	588.	10.085
TAKEN AT 121.3 SECONDS															
121.3	24.41	598.	1278.	1396.	1606.	1649.	1410.	1555.	588.	1359.	1412.	1639.	599.	588.	10.245
181.3	24.47	613.	1317.	1400.	1616.	1684.	1421.	1603.	588.	1376.	1424.	1648.	599.	588.	10.420
201.2	24.48	648.	1348.	1414.	1624.	1661.	1431.	1568.	618.	1380.	1435.	1654.	598.	587.	10.515
301.3	24.44	721.	1396.	1428.	1633.	1667.	1441.	1572.	677.	1406.	1446.	1664.	598.	587.	10.938
401.2	24.43	772.	1420.	1437.	1638.	1673.	1446.	1575.	727.	1415.	1452.	1671.	599.	587.	11.165
501.2	24.42	806.	1434.	1441.	1637.	1673.	1449.	1575.	765.	1419.	1455.	1673.	590.	588.	11.285
601.2	24.40	830.	1443.	1444.	1638.	1676.	1451.	1577.	792.	1422.	1457.	1676.	592.	590.	11.365

ARO, INC.-AEBC DIVISION  
 A SVERDRUP CORPORATION COMPANY  
 VON KARMAN GAS DYNAMICS FACILITY  
 ARNOLD AIR FORCE STATION, TENNESSEE  
 NASA/AMES AFAS1 MATERIALS TEST

TC 11 10 14  
 SYM □ ○ △

RUN 26



2. Plotted Data

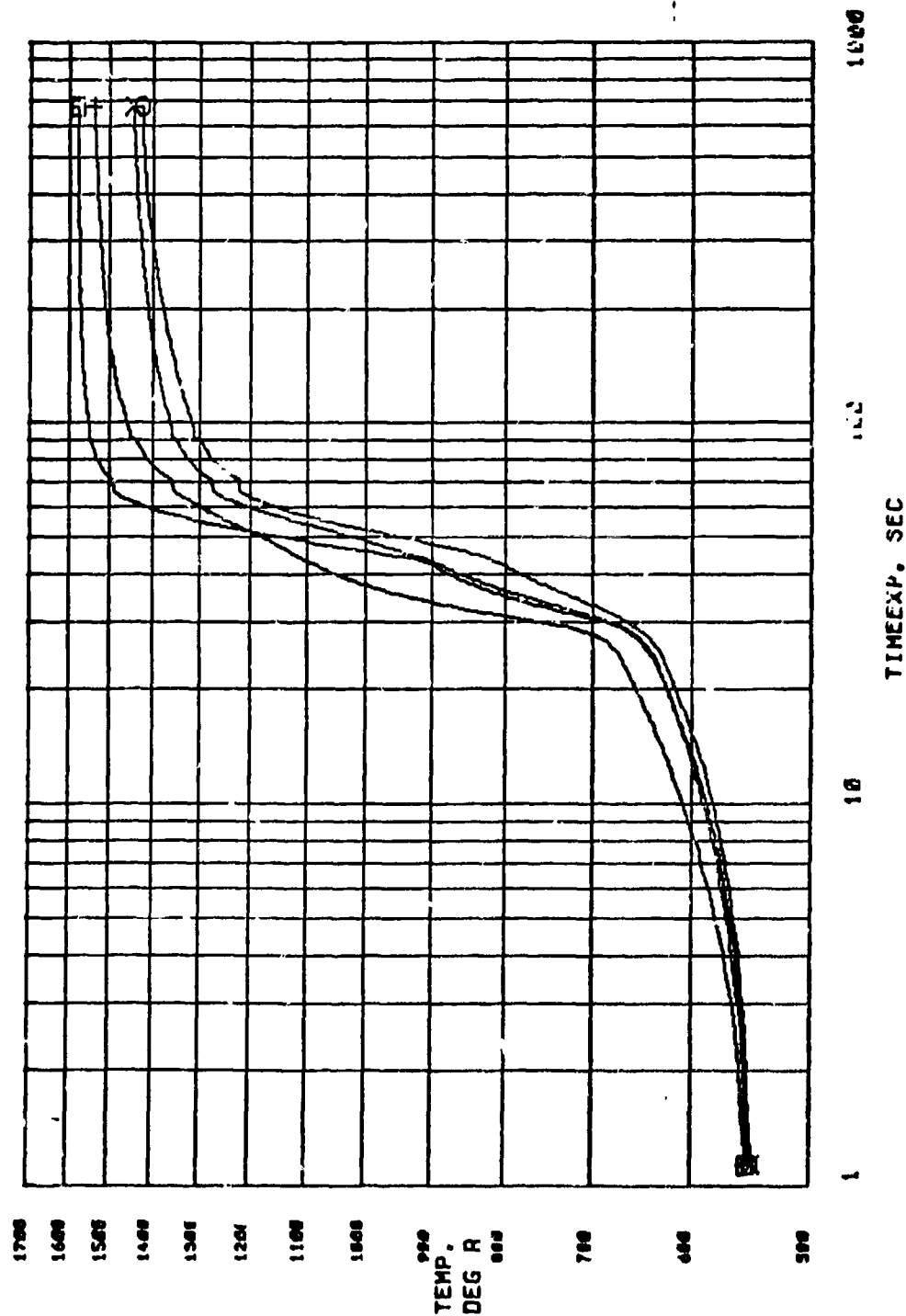


ARO, INC.-REDC DIVISION  
 A SVERDRUP CORPORATION COMPANY  
 VON KARMAN GAS DYNAMICS FACILITY  
 ARNOLD AIR FORCE STATION, TENNESSEE  
 NASA/AMES AFAS1 MATERIALS TEST

RUN  
 26

SYM  
 □□+X

TC  
 1 2 3 4

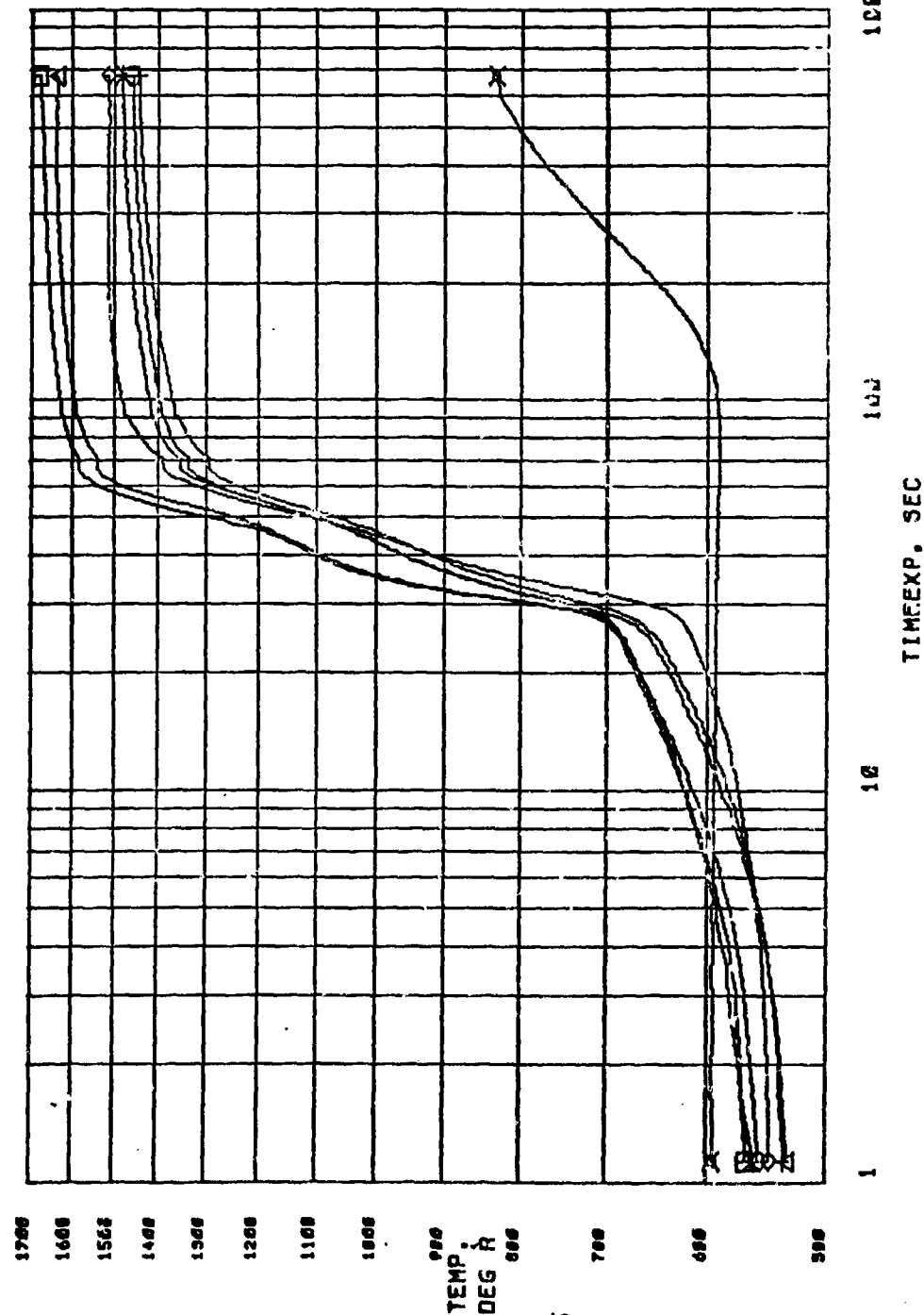


ARO, INC.-AE0C DIVISION  
 A SVERDRUP CORPORATION COMPANY  
 VON KARMAN GAS DYNAMICS FACILITY  
 ARNOLD AIR FORCE STATION, TENNESSEE  
 NASA/AMES AFAS1 MATERIALS TEST

RUN  
 26

SYN  
 □ ⊙ △ + ◇ ✱ ✕

TC  
 23  
 22  
 16  
 15  
 5  
 6  
 .13

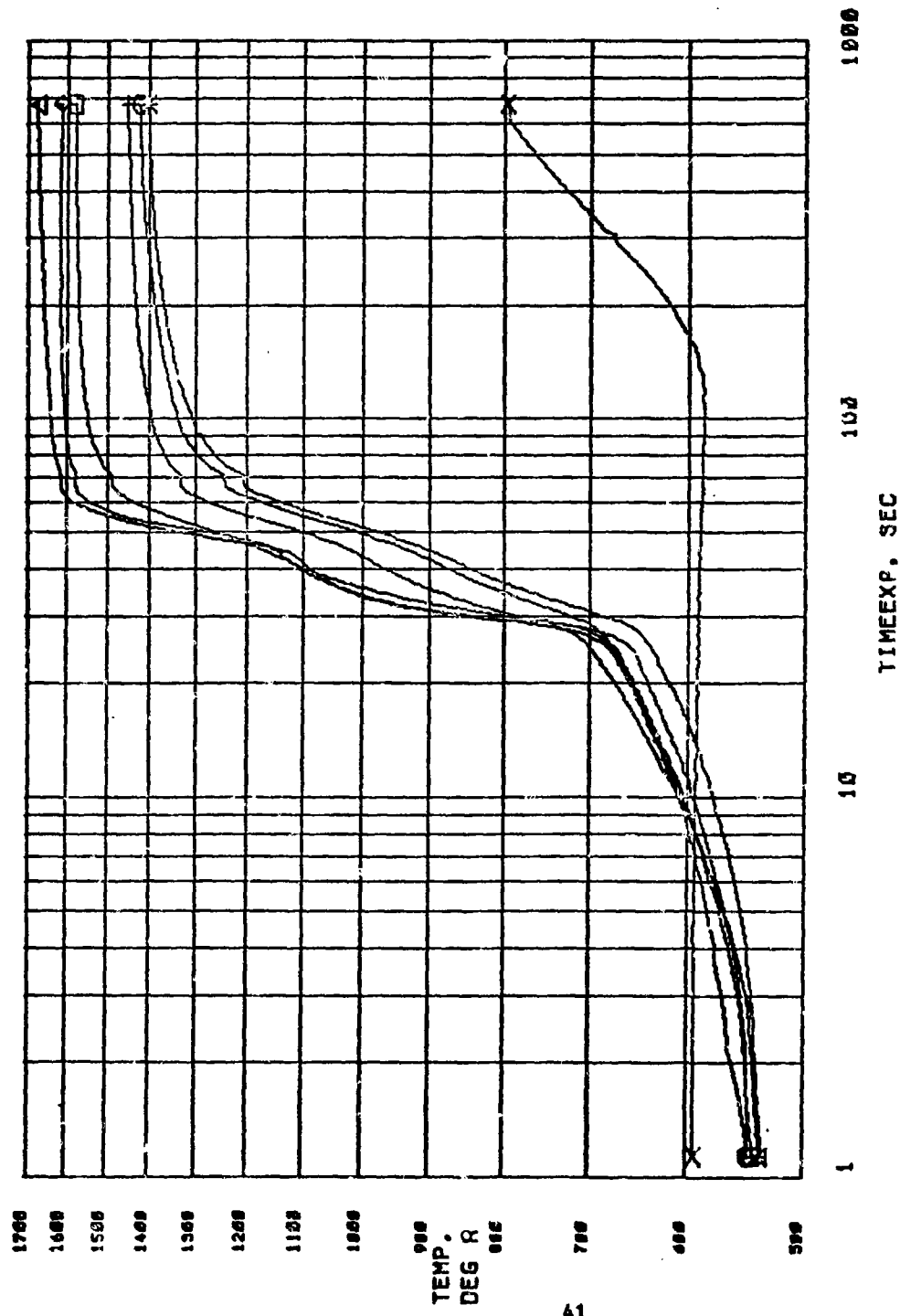


ARO, INC.--AEDC DIVISION  
 A SVERDRUP CORPORATION COMPANY  
 VON KARMAN GAS DYNAMICS FACILITY  
 ARNOLD PIA FORCE STATION, TENNESSEE  
 NASA/AMES AFRL MATERIALS TEST

RUN  
 26

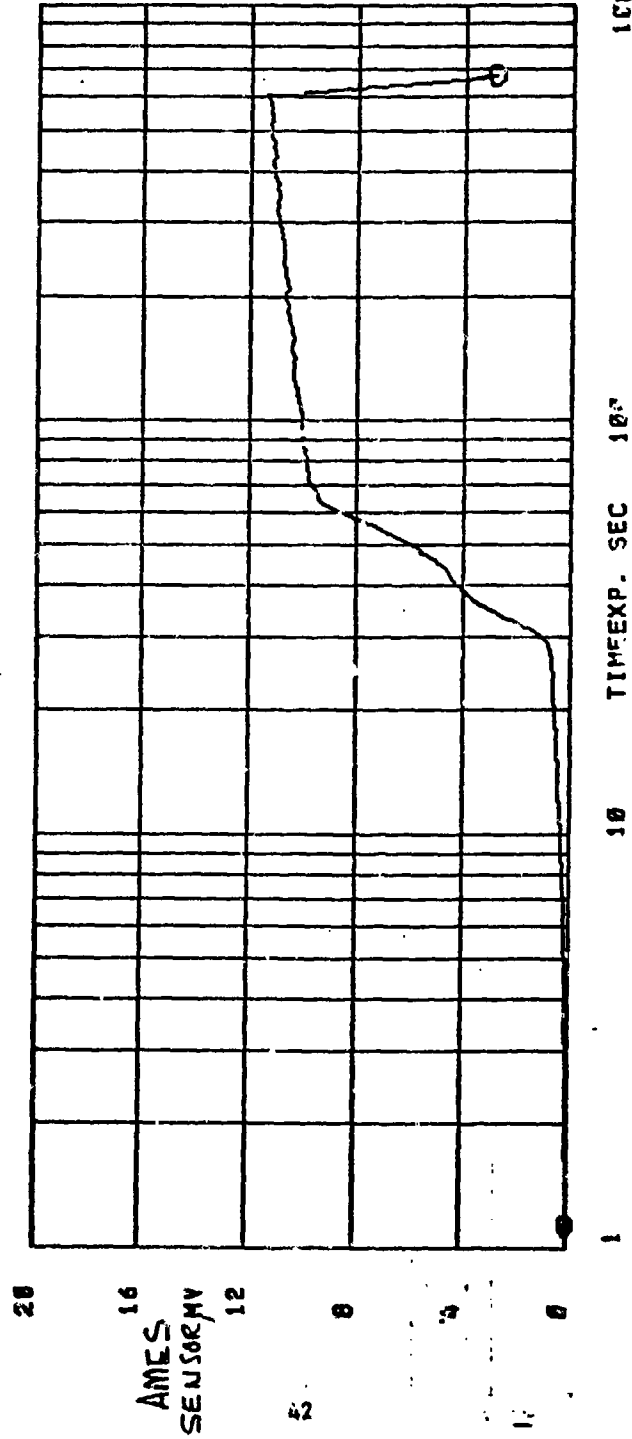
SYM  
 □ ○ △ + × ◇ \*

TC  
 19 21 17 18 20  
 7 8

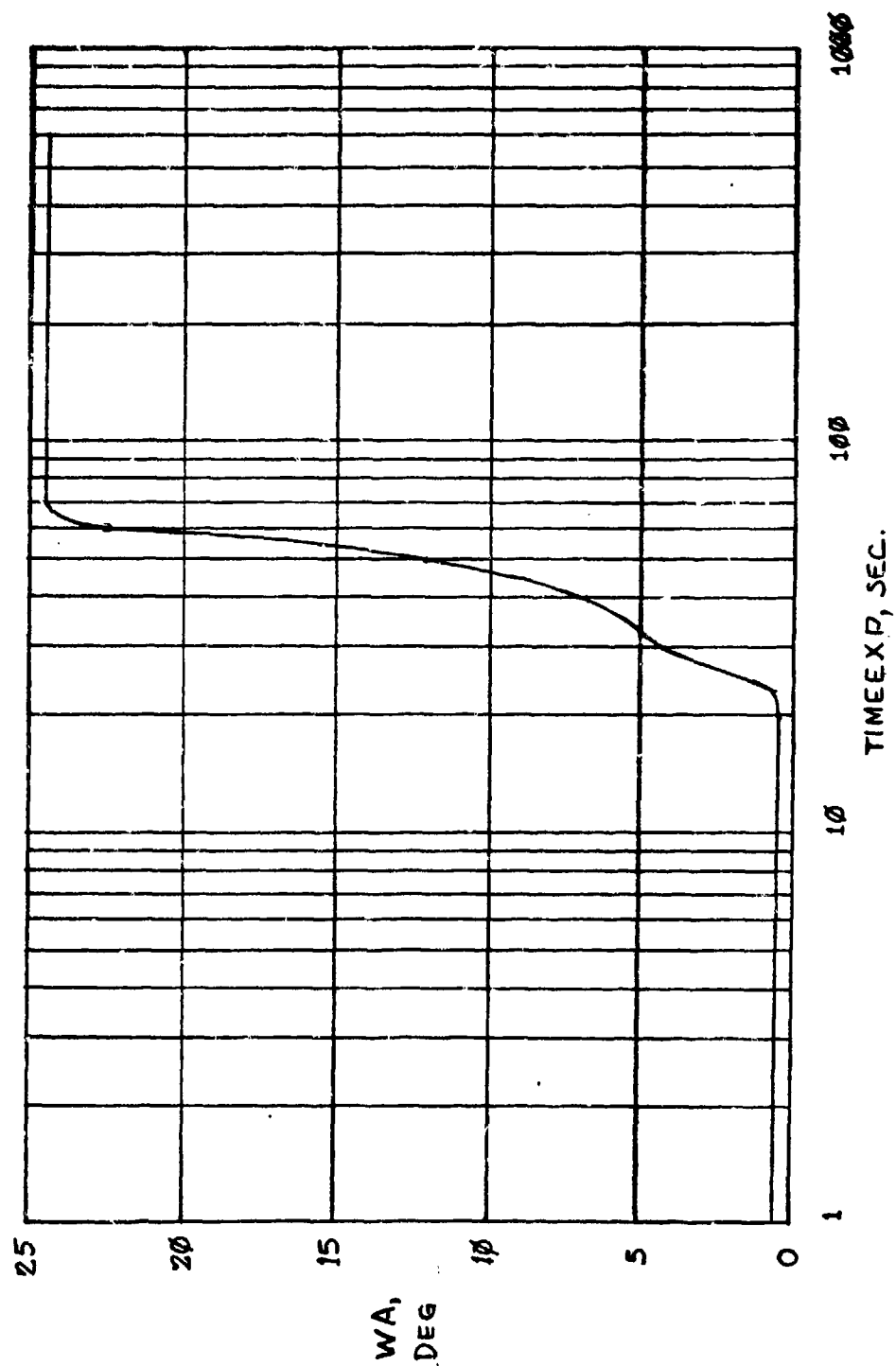


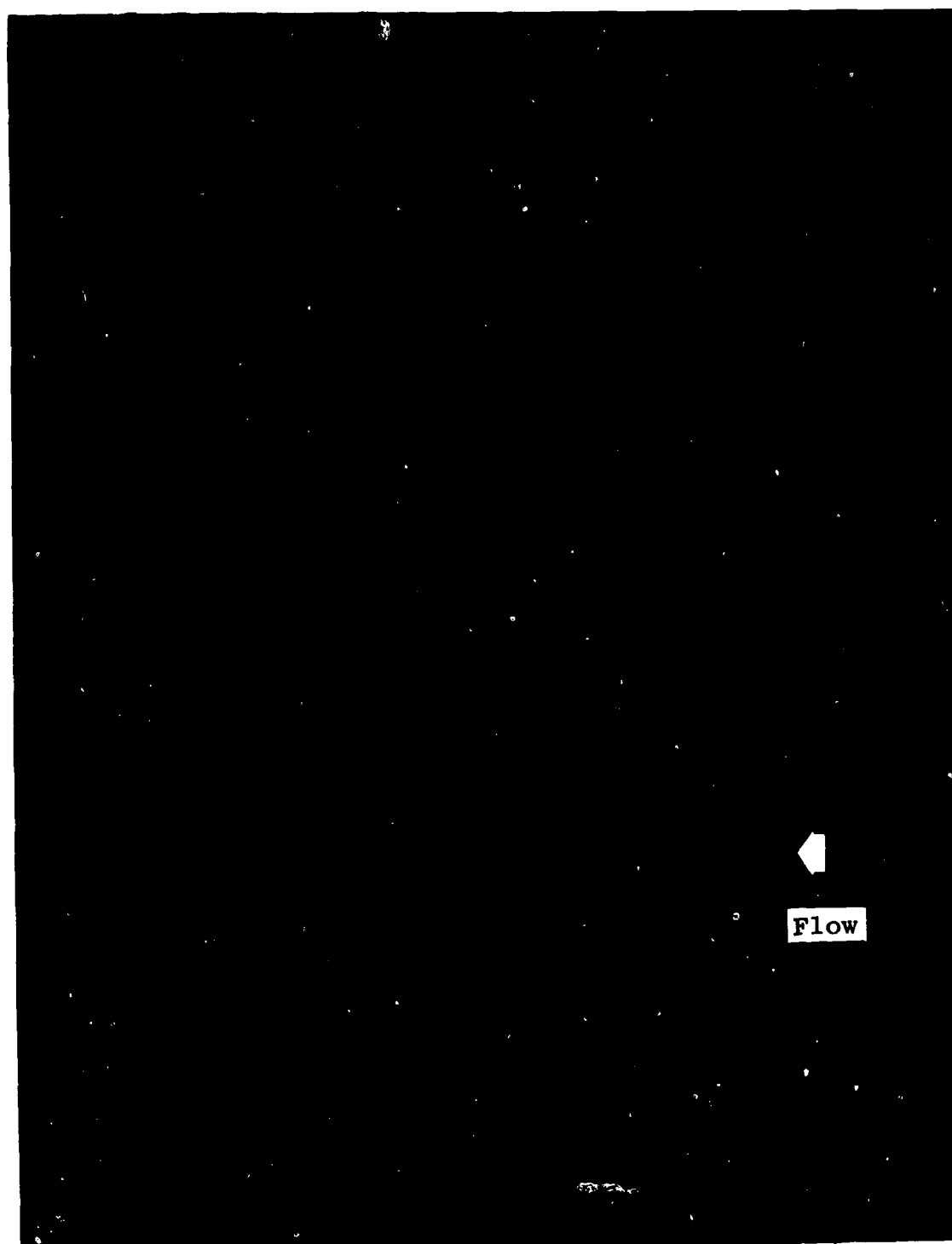
ARO, INC.-REDC DIVISION  
 A SVERDRUP CORPORATION COMPANY  
 VON KARMAN GAS DYNAMICS FACILITY  
 ARNOLD AIR FORCE STATION, TENNESSEE  
 NASA/AMES AFRL MATERIALS TEST

RUN 26  
 SYM TC  
 SENSOR



RUN  
26





A horizontal timeline for the 1500s, starting at 1459 and ending at 1794. Major tick marks are labeled every 10 years: 1459, 1503, 1544, 1584, 1622, 1658, 1694, 1728, 1762, and 1794. The timeline is represented by a horizontal line with vertical tick marks at each year.

Color Bar Temperature Calibration  
(from Table 2), °R

### 3. Typical IR Photograph of Surface Temperature